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FLUID-ASSISTED MEDICAL DEVICES, SYSTEMS AND METHODS

This application is being filed as a PCT International Patent application in the name of TissueLink Medical, Inc. (a U.S. national corporation), for the designation of all countries except the U.S., and Michael E. McClurken, David Lipson, Arnold E. Oyola and David Flanagan (all U.S. citizens), for the designation of the US only, on May 15, 2003.

Field

This invention relates generally to the field of medical devices, systems and methods for use upon a body during surgery. More particularly, the invention relates to electrosurgical devices, systems and methods for use upon tissues of a human body during surgery, particularly open surgery and minimally invasive surgery such as laparoscopic surgery.

Background

The application of heat to tissue, typically from a flame heated metal object, has been used for centuries to cauterize bleeding wounds. In cauterization, the essential mechanism behind tissue treatment involves raising the temperature of the bleeding tissue by conductive heat transfer from the heated metal object. In order to arrest bleeding from the tissue's severed blood vessels, the tissue is heated adequately to shrink certain tissue proteins, such as collagen, thus closing the blood vessels and ultimately leading to blood vessel thrombosis.

Apart from shrinkage, the application of compressive force from a heated metal object to a blood vessel may also result in collagen welding, such as for the permanent joining together of opposite walls of a blood vessel, thus providing another mechanism of hemostasis in addition to simple shrinkage of collagen.

With the aid of electricity, cauterization spurred the development of electrocautery devices to treat bleeding. While electrocautery devices still involve the use of a heated metal object, the electrocautery device is heated via electrical energy converted to heat in the metal object as opposed to heating the metal with a direct flame.

More recently, coagulation may be accomplished by radio frequency ("RF") electrosurgical devices where electrical energy is converted to heat in the tissue rather than in the device. Heating of the tissue is often performed by means of resistance heating. In other words, increasing the temperature of the tissue as a result of electric current flow through the tissue which is resisted by the tissue.

Electrical energy is converted into thermal energy (i.e. heat) via accelerated movement of ions as a function of the tissue's electrical resistance and current flow.

Hemostasis of the above sort is not without its drawbacks. Current dry tip RF electrosurgical devices can cause the temperature of tissue being treated to rise significantly higher than 100 °C, thus exceeding the boiling temperature of inter-cellular water and resulting in tissue desiccation, tissue sticking to the electrodes, tissue perforation, char formation and smoke generation. Peak tissue temperatures at a targeted tissue treatment site can be as high as 320 °C as a result of RF treatment, and such high temperatures can be transmitted to adjacent untargeted tissue via conduction. Undesirable results of such transmission to untargeted adjacent tissue include unintended thermal damage to the untargeted tissue.

According to U.S. Patent No. 6,086,586 to Hooven entitled "Bipolar Tissue Grasping Apparatus and Tissue Welding Method", currently-available bipolar grasping instruments for electro-coagulation of tissue, or "tissue welding," generally use only two electrodes of opposite polarity, one of which is located on each of the opposite jaws of the grasper. As illustrated in Hooven's FIG. 1, in use, tissue is held between a pair of grasper jaws (shown in cross-section) having first and second electrodes (Electrode 1 and Electrode 2) of opposite polarity. Bipolar current flows between the two electrodes along the illustrated current flow lines, with tissue coagulating first at the edges of the jaws. Then, as the tissue dries out and the impedance increases, the current flows through the moister tissue and the coagulation spreads both inward toward the center of the jaws and outward from the jaw edges.

The Hooven patent goes on to recite that "[t]hermal damage to adjacent structures can occur due to this spread of thermal energy outside the jaws of the instrument. Because of the spread of thermal energy outside the jaws of the instrument, it is difficult to coagulate long sections of tissue, such as bowel, lung, or larger blood vessels, without significant lateral thermal spread. Over-coagulation frequently occurs, resulting in tissue sticking to the jaws of the instrument. When the jaws of the instrument are opened, if the tissue sticking is severe, the tissue can be pulled apart, thus adversely affecting hemostasis."

As part of the summary of the invention, the Hooven patent recites "a bipolar electrosurgical instrument having a pair of relatively moveable jaws, each of which includes a tissue contacting surface. The tissue contacting surfaces of the jaws are in face-to-face relation with one another, and adjacent each of the tissue contacting surfaces are first and second spaced-apart electrodes that are adapted for connection to the opposite terminals of a bipolar RF generator so as to generate a current flow therebetween." Furthermore, the Hooven patent recites that, "[b]ecause each jaw is

a bipolar electrode, multiple local current pathways, high current densities, and lower impedances are achieved. Indeed, the maximum current density is between the two insulated jaw surfaces, while a relatively lower current density exists at the electrode surfaces."

However, the invention of the Hooven patent encounters certain difficulties. Due to tissue irregularities, the surface of the tissue to be treated may be uneven or undulated with peaks and valleys. Consequently, the area of electrical coupling of the tissue to the electrode surfaces can be limited to the isolated peaks in the tissue surface. In this situation, upon the application of RF power to tissue, the electrical coupling of only the tissue peaks to the electrode surfaces may result in corresponding increase in current density through the electrically coupled peaks which has the ability to desiccate and char the tissue at these isolated locations. Hooven does not address or provide for this situation.

Another difficulty encountered with the Hooven invention is that it does not address or provide for a decreasing electrical coupling between the tissue and electrode surfaces upon tissue shrinkage and/or desiccation during treatment. As tissue shrinks and/or desiccates during treatment, the tissue surfaces may loose contact with the electrode surfaces which, similar to above, decreases the area of electrical coupling therebetween and correspondingly increases the current density and associated heat at the locations which remain electrically coupled. This difficulty is further exacerbated if the tissue is undulated as described above.

Another difficulty encountered with the Hooven invention is that it does not address or provide for dissipating heat from the insulating members. Hooven does not address or provide how heat which may be conducted into the insulating members from the tissue between the two insulated surfaces is subsequently removed from the insulating members.

In light of the above, it is an object of the invention to provide devices, systems and methods which overcome the limitations of the art.

Summary of the Invention

The present invention provides devices, systems and methods that inhibit, and more preferably minimize or prevent, tissue necrosis outside a targeted tissue treatment site during a medical procedure. The invention is particularly useful during surgical procedures upon tissues of a human body, where it is desirable to coagulate and shrink tissue, to occlude lumens of blood vessels (e.g. arteries, veins), airways (e.g. bronchi, bronchioles), bile ducts and lymphatic ducts.

According to the present invention, electrosurgical devices, systems and methods are provided in which the electrical current paths, associated electrical

resistance heating and ensuing thermal conduction heating are substantially limited to tissue within the jaws of the device, so as to inhibit, and preferably prevent, tissue damage outside the jaws due to thermal effects. More preferably, the electrical current paths, as well as current density, are concentrated within the confines and borders of two electrically insulated surfaces of the jaws and, even more preferably, within the medial portions of the electrically insulated surfaces.

According to the present invention, electrosurgical devices, systems and methods are provided in which the maximum current density and heating of tissue (by both electrical resistance heating and thermal conduction heating) occurs apart or removed from the electrodes and preferably between the two electrically insulated surfaces. More preferably, the electrodes are configured such that the portion of the electrode surfaces closest to the two electrically insulated surfaces is remotely located and separated from the electrically insulated surfaces.

According to the present invention, electrosurgical devices, systems and methods are provided in which the electrical coupling between tissue and the electrodes is enhanced, so as to inhibit tissue damage outside the electrically insulated surfaces, particularly to tissue nearest the electrodes. Tissue damage can be manifest in many ways, depending on the tissue temperature encountered, ranging from coagulation necrosis at temperatures from 50 to 100 °C, to sticking at temperatures above 120 °C, to charring, arcing and smoke formation at temperatures exceeding 200 °C.

According to the present invention, preferably the enhanced electrical coupling is provided by an electrically conductive fluid which couples between the tissue surface and the electrodes and increases the uniformity of the electrical coupling therebetween. In addition to inhibiting tissue damage as outlined above, this enhancement is particularly useful to counter poor electrical coupling associated with prior art dry devices, uneven and undulated tissue, shrinkage of treated tissue, desiccation of treated tissue and motion of the jaws while grasping tissue.

According to the present invention, electrosurgical devices, systems and methods are provided in which a portion of the electrical current, upon exiting from between the two electrically insulated surfaces, flows at least partially through the electrically conductive fluid, rather than through the tissue outside the electrically insulated surfaces, before reaching the counter electrode. According to the present invention, this will inhibit tissue damage outside the electrically insulated surfaces given the decrease in electrical current through the tissue and associated decrease in power in the tissue will correspondingly reduce the amount of resistance and conduction heating of the tissue.

According to the present invention, electrosurgical devices, systems and methods are provided and configured to provide a diversion and preferably divert at least a portion of the electrical current, upon exiting from between the two electrically insulated surfaces, at least partially through the conductive fluid before reaching the counter electrode. Preferably at least a portion of the electrically conductive fluid coupling the electrodes and the tissue outside the electrically insulated surfaces electrical couples tissue adjacent the electrically insulated surfaces. Also, preferably, at least a portion of the electrically conductive fluid coupling the electrodes and the tissue adjacent the electrically insulated surfaces electrical couples the tissue and the electrodes at the shortest distance there between.

Preferably the electrosurgical devices, systems and methods are configured such that the electrical current exiting from between the two electrically insulated surfaces will be more apt to be concentrated and flow at least partially through the electrically conductive fluid, rather than through the tissue outside the electrically insulated surfaces, to the counter electrode.

Preferably the electrically conductive fluid is provided in a configuration to present an electrical resistance to the electrical current exiting from between the two electrically insulated surfaces which is less than the electrical resistance encountered in tissue outside the electrically insulated surfaces. Preferably the electrically conductive fluid has an electrical resistivity less than the electrical resistivity of the tissue through which electrical current would flow in the absence of the electrically conductive fluid prior to treatment with the device.

According to the present invention, the source electrode side relative to the tissue grasping surfaces is configured similar to the counter electrode side. As electrical current flows from the source electrode and enters between the tissue grasping surfaces it will also seek a path to the counter electrode comprising the least electrical resistance. Consequently, in addition to the above, the device is also configured to provide a diversion for and preferably divert at least a portion of the electrical current, upon leaving the source electrode, at least partially through the conductive fluid before entering between the grasping surfaces.

Preferably the electrically conductive fluid is provided to tissue by means of the electrosurgical device. Also preferably, the electrically conductive fluid comprises a saline solution. Furthermore, in certain embodiments, the saline solution may comprise physiologic saline or hypertonic saline.

According to the present invention, electrosurgical devices, systems and methods are provided in which removal of heat from and cooling of the tissue outside the electrically insulated surfaces is enhanced, so as to inhibit tissue damage outside the electrically insulated surfaces. Preferably, the enhanced cooling is

provided by a fluid, particularly the electrically conductive fluid. More particularly, in the event a portion of the electrical current exiting from between the two electrically insulated surfaces flows through tissue outside the electrically insulated surfaces, thus heating the tissue outside the electrically insulated surfaces by resistance and conduction heating, the conductive fluid function as a heat sink to absorb and remove heat from the tissue and cool the tissue. Furthermore, it is an object of the present invention that the conductive fluid lubricates the tissue/electrode interface and the tissue/electrically insulated surface interface as to inhibit sticking thereto.

According to the present invention, electrosurgical devices, systems and methods are provided which are configured to remove heat from and cool the jaws, particularly the electrically insulated surfaces of the jaws, and more particularly the medial portion of the insulated surfaces. In some embodiments, the electrically insulated surfaces of the jaws comprise or are supported by a material with a high thermal conductivity. In other embodiments, heat is removed from the jaws by the electrically conductive fluid.

According to the present invention, electrosurgical devices, systems and methods are provided for medical procedures, which preferably utilize radio frequency ("RF") power and electrically conductive fluid during the treatment of tissue. Preferably, the temperature of the tissue, particularly outside a targeted tissue treatment site (e.g. outside the electrically insulated surfaces of the jaws), may be altered and at least partially controlled (e.g. maintained within a targeted temperature range or at a targeted tissue temperature) by adjusting parameters (e.g. the fluid flow rate of the electrically conductive fluid) that affect the temperature of the tissue.

According to the present invention, using a fluid in the above manner inhibits, and preferably minimizes or prevents tissue damage (e.g. necrosis), and such undesirable effects as tissue sticking to electrodes, smoke generation, char formation and desiccation, to tissue outside a targeted tissue treatment site.

According to the present invention, a tissue grasping device is provided comprising a tip portion including a first jaw and a second jaw with at least one of the jaws being movable toward the other jaw. The first jaw includes a first tissue grasping surface and the second jaw includes a second tissue grasping surface. The tissue grasping surface of each jaw has a length defined by proximal and distal ends, a width defined by edges and further comprises an electrically insulative surface. The device further comprises first and second electrodes being connectable to different terminals of a radio frequency generator to generate electrical current flow therebetween, with the first electrode having a first electrode surface and the second

electrode having a second electrode surface. One of the first and second electrode surfaces is located on one or the other of the jaws separated from one edge of the tissue grasping surface and the other of the electrode surfaces is located on one or the other of the jaws separated from the other edge of the tissue grasping surface. The device also includes at least one fluid passage being connectable to a fluid source.

According to the present invention, a device is provided with a tip portion configured to provide radio frequency power from a radio frequency generator with a fluid from a fluid source to tissue, with the fluid provided to the tissue at a tissue surface and the radio frequency power provided to the tissue below the tissue surface.

According to another aspect of the present invention, a device is provided with a tip portion configured to provide radio frequency power to tissue at least partially through a fluid coupling located on a surface of the tissue, with the fluid coupling comprising an electrically conductive fluid provided from a fluid source and the electrically conductive fluid provided from the tip portion with the radio frequency power.

According to another aspect of the invention, a device is provided that is configured to receive radio frequency power from a radio frequency generator at a power level and an electrically conductive fluid from a fluid source at a fluid flow rate, and deliver the electrically conductive fluid to tissue at a tissue surface and the radio frequency power to the tissue below the tissue surface.

According to yet another aspect to the invention, a device is provided that is configured to receive radio frequency power from a radio frequency generator at a power level and an electrically conductive fluid from a fluid source at a fluid flow rate, and deliver the electrically conductive fluid to tissue at a tissue surface and the radio frequency power to the tissue below the tissue surface at least partially through a fluid coupling comprising the electrically conductive fluid.

In certain embodiments, the tip portion further comprises at least one fluid outlet in fluid communication with a fluid passage configured to provide a fluid from a fluid source to tissue. Preferably, the at least one fluid outlet in fluid communication with the fluid passage further comprises a first fluid outlet and a second fluid outlet with the first fluid outlet being located on the same jaw as a first electrode and the second fluid outlet being located on the same jaw as a second electrode. Preferably, the first fluid outlet and the second fluid outlet are configured to receive the fluid from the fluid source and provide the fluid to tissue located outside of tissue grasping surfaces.

In one embodiment, a first fluid outlet and a second fluid outlet are configured to receive a fluid from a fluid source and provide the fluid to tissue located outside of and adjacent tissue grasping surfaces.

In another embodiment, a first fluid outlet and a second fluid outlet are configured to receive a fluid from a fluid source and provide the fluid to tissue located outside of and separated from tissue grasping surfaces.

In another embodiment, a first fluid outlet is configured to provide a fluid to tissue located adjacent a first electrode surface, and a second fluid outlet is configured to provide a fluid to tissue located adjacent a second electrode surface.

In another embodiment, a first fluid outlet is configured to provide a fluid between a first electrode surface and tissue, and a second fluid outlet is configured to provide a fluid between a second electrode surface and tissue.

In another embodiment, a first fluid outlet is configured to provide a fluid between a first electrode surface and one edge of one or the other of two tissue grasping surfaces, and a second fluid outlet is configured to provide a fluid between a second electrode surface and the other edge of one or the other of the tissue grasping surfaces.

In another embodiment, a first fluid outlet is configured to provide a fluid to the first electrode surface, and a second fluid outlet is configured to provide a fluid to a second electrode surface.

In another embodiment, a first fluid outlet is configured to provide a fluid to a first portion of one or the other of two jaws outside a tissue grasping surface, and a second fluid outlet is configured to provide a fluid to a second portion of one or the other of the jaws outside a tissue grasping surface.

In one embodiment, each of two first and second electrode surfaces is separated from a tissue grasping surface of a jaw to which it is located by a gap. In another embodiment, at least a portion of each gap separating each of the first and second electrode surfaces from the tissue grasping surface of the jaw to which it is located is configured to receive a fluid from a fluid source. In another embodiment, the fluid received by each of the gaps is configured to provide a fluid coupling which provides cooling and removing heat from tissue located outside the tissue grasping surfaces. In yet another embodiment, the fluid comprises an electrically conductive fluid, and the fluid received by each of the gaps is configured to provide a fluid coupling which enhances the electrical connection of the first and second electrode surfaces and tissue located outside the tissue grasping surfaces. Furthermore, in yet another embodiment, at least a portion of the electrical current flow between the first and second electrode surfaces may be caused to flow at least partially through at least one fluid coupling as opposed to tissue located outside the

tissue grasping surfaces, whereby the amount of current flow through tissue located outside the tissue grasping surfaces may be correspondingly reduced. In one embodiment, the tissue grasping surface of each jaw has a length, and each gap further comprises an elongated gap separating each of the first and second electrode surfaces from the tissue grasping surface of the jaw to which it is located along the length of the tissue grasping surface. In another embodiment, at least a portion of each elongated gap separating each of the first and second electrode surfaces from the tissue grasping surface of the jaw to which it is located is configured to receive a fluid from the fluid source and provide a fluid flow channel for the fluid along the length of the tissue grasping surface.

In yet another embodiment, at least one jaw comprises at least one stand-off configured to keep tissue from physically contacting at least one of a first electrode surface and a second electrode surface. In various embodiments, the stand-off preferably comprises a coil wrapped around at least a portion of one of the first and second electrode surface, a material porous to a fluid provided from a fluid source there through with the material overlying at least a portion of one of the first and second electrode surface, or a foam material overlying at least a portion of one of the first and second electrode surface. In other embodiments, the stand-off comprises a polymer or ceramic material.

In other embodiments, at least one jaw comprises at least one obstruction configured to inhibit a fluid shunt from forming between the first electrode and the second electrode. In various embodiments, the obstruction comprises a tissue grasping surface of a jaw, a distal end portion of a jaw, a proximal end portion of a jaw or a backside portion of a jaw, such as a protrusion or recess which provides a drip edge.

In other embodiments, a tissue treatment indicator is provided which provides an output related to a level of treatment of tissue. In certain embodiments, the tissue treatment indicator comprises a bulb or a thermochromic device wired in parallel with an electrode.

According to another aspect of the invention, a tissue grasping device is provided comprising a tip portion including a first jaw and a second jaw with at least one of the jaws being movable toward the other jaw. Each jaw includes a left-side portion, a right-side portion and a tissue grasping surface with the tissue grasping surface of each jaw further comprising an electrically insulative surface. The device further comprises first and second electrodes being connectable to different terminals of a radio frequency generator to generate electrical current flow therebetween with the first electrode having a first electrode surface and the second electrode having a second electrode surface. One of the first and second electrodes

is located on one or the other of the jaws on the left-side portion of the jaw and the other of the electrodes is located on one or the other of the jaws on the right-side portion of the jaw. Each of the first and second electrode surfaces is separated from the tissue grasping surface of the jaw on which it is located. The device also includes at least one fluid passage being connectable to a fluid source.

According to another aspect of the invention, a tissue grasping device is provided comprising a tip portion including a first jaw and a second jaw with at least one of the jaws being movable toward the other jaw. Each jaw includes a tissue grasping surface with the tissue grasping surface of each jaw further comprising an electrically insulative surface. A portion of each tissue grasping surface is located on each side of a center plane. The center plane is orientated longitudinal and to the tissue grasping surface. The device further comprises first and second electrodes being connectable to different terminals of a radio frequency generator to generate electrical current flow therebetween with the first electrode having a first electrode surface and the second electrode having a second electrode surface. One of the first and second electrodes is located on one or the other of the jaws on one side of the center plane and the other of the electrodes is located on one or the other of the jaws on the other side of the center plane. Each of the first and second electrode surfaces is separated from the tissue grasping surface of the jaw to which it is located. The device also includes at least one fluid passage being connectable to a fluid source.

According to another aspect of the invention, a tissue grasping device is provided comprising a tip portion including a first jaw and a second jaw with at least one of the jaws being movable toward the other jaw. Each jaw includes a tissue grasping surface with the tissue grasping surface of each jaw further comprising an electrically insulative surface. A portion of each tissue grasping surface is located on two opposing sides of a cutting mechanism, the cutting mechanism comprising a blade. The device further comprises first and second electrodes being connectable to different terminals of a radio frequency generator to generate electrical current flow therebetween with the first electrode having a first electrode surface and the second electrode having a second electrode surface. One of the first and second electrodes is located on one or the other of the jaws on one side of the cutting mechanism and the other of the electrodes is located on one or the other of the jaws on the other side of the cutting mechanism. Each the first and second electrode surfaces is separated from the tissue grasping surface of the jaw to which it is located. The device also includes at least one fluid passage being connectable to a fluid source.

According to another aspect of the invention, a tissue grasping device is provided comprising a tip portion including a first jaw and a second jaw with at least one of the jaws being movable toward the other jaw. Each jaw includes a tissue

grasping surface with the tissue grasping surface of each jaw further comprising an electrically insulative surface. The device further comprises at least two spaced-apart electrode surfaces separated from the tissue grasping surface of each jaw, with the two electrode surfaces on the first jaw in direct opposed relation with the two electrode surfaces on the second jaw, the opposing electrode surfaces being of like polarity and the electrode surfaces of each jaw being connectable to a power source for providing electrical current flow therebetween. The device also includes at least one fluid passage being connectable to a fluid source.

According to another aspect of the invention, a method of treating tissue is provided comprising providing tissue; providing electrical current; providing a fluid; providing a first tissue grasping surface and a second tissue grasping surface; grasping a first portion of tissue with the first portion of tissue located between the tissue grasping surfaces; providing the fluid to a second portion of tissue with the second portion of tissue located outside the tissue grasping surfaces; providing the electric current to the tissue; and directing the electric current in the first portion of tissue to flow across the tissue grasping surfaces. In certain embodiments, the method further comprises the step of cooling the second portion of tissue with the fluid and/or cooling the first portion of tissue with the fluid. Furthermore, in certain embodiments, the step of providing a fluid further comprises providing an electrically conductive fluid, and the method includes the additional step of reducing the electrical current in the second portion of tissue with the fluid.

According to another aspect of the invention, a method of treating tissue is provided comprising providing tissue; providing electrical current; providing a fluid; providing a first tissue grasping surface and a second tissue grasping surface; grasping a first portion of tissue, the first portion of tissue located between the tissue grasping surfaces; providing the fluid to a second portion of tissue, the second portion of tissue located outside the tissue grasping surfaces; providing the electric current to the tissue; and directing the electric current in the first portion of tissue to flow substantially parallel to the tissue grasping surfaces. In certain embodiments, the method further comprises the step of cooling the second portion of tissue with the fluid and/or cooling the first portion of tissue with the fluid. Furthermore, in certain embodiments, the step of providing a fluid further comprises providing an electrically conductive fluid, and the method includes the additional step of reducing the electrical current in the second portion of tissue with the fluid.

According to another aspect of the present invention, a tissue grasping device is provided comprising a tip portion including a first jaw and a second jaw with at least one of the jaws being movable toward the other jaw. Each jaw includes a tissue grasping surface with the tissue grasping surface of each jaw further

comprising an electrically insulative surface. The device further comprises at least two electrodes separated by the tissue grasping surfaces and located between the two electrodes with the two electrodes being connectable to different terminals of a radio frequency generator to generate electrical current flow therebetween. The device also includes at least one fluid passage being connectable to a fluid source.

According to another aspect of the invention, a tissue grasping device of the present invention may be provided with at least one electrical transformer coupled to the first and second electrodes. In various embodiments, the transformer may further comprise a voltage transformer, an impedance transformer, an autotransformer, a single coil transformer, a transformer having a first coil electrically insulated from a second coil or a step-up transformer. In another embodiment, the at least one electrical transformer may further comprise a first transformer and a second transformer coupled in series to the first and second electrodes, with the first transformer comprising an impedance transformer and the second transformer comprising an autotransformer.

The invention is also directed to various embodiments of an adaptor for electrically coupling between an electrosurgical generator and a bipolar electrosurgical device. In one embodiment, the adaptor comprises a power input connector for coupling the adaptor with a monopolar mode power output connector of the electrosurgical generator, a ground connector for coupling the adaptor with a ground connector of the electrosurgical generator, a first and a second power output connector, each for coupling the adaptor with a first and a second bipolar mode power input connector of the bipolar electrosurgical device, respectively, and at least one electrical transformer coupled between the power input connector and the first and second power output connectors with the transformer comprising an autotransformer. In various embodiments, the adaptor may further comprise a monopolar hand switch connector for coupling the adaptor with a monopolar mode hand switch connector of the electrosurgical generator, and at least one bipolar mode hand switch connector for coupling the adaptor with a bipolar mode hand switch connector of the electrosurgical device. In other embodiments, the adaptor may further comprise a first and a second bipolar mode hand switch connector for coupling the adaptor with a first and a second bipolar mode hand switch connector of the electrosurgical device, respectively. Moreover, in other embodiments, the first bipolar mode hand switch connector is coupled to the monopolar hand switch connector, and the second bipolar mode hand switch connector is coupled to the power input connector in parallel with the transformer, whereby the coupling bypasses the transformer.

In other embodiments, the adaptor may comprise a pair of bipolar power input connectors for coupling the adaptor with a pair of bipolar power output connectors of the electrosurgical generator, a pair of bipolar power output connectors for coupling the adaptor with a pair of bipolar power input connectors of the bipolar electrosurgical device; and at least one electrical transformer coupled between the bipolar power input connectors and the bipolar power output connectors. In various embodiments, the adaptor may further comprise a first electrical transformer and a second electrical transformer coupled in series and between the power input connector and the first and second power output connectors, with the first transformer comprising an impedance transformer and the second transformer comprising an autotransformer. In other embodiments, the adaptor may comprise a bipolar hand switch input connector for coupling the adaptor with a bipolar hand switch output connector of the electrosurgical generator, and at least one bipolar mode hand switch output connector for coupling the adaptor with a bipolar mode hand switch input connector of the electrosurgical device. In still other embodiments, the adaptor may further comprise a first and a second bipolar mode hand switch output connector for coupling the adaptor with a first and a second bipolar mode hand switch input connector of the electrosurgical device, respectively. Moreover, in still other embodiments, the first bipolar mode hand switch output connector is coupled to the bipolar hand switch input connector, and the second bipolar mode hand switch output connector is coupled to one of the bipolar power input connectors in parallel with the impedance transformer and the autotransformer, whereby the coupling bypasses the transformers.

Brief Description Of The Drawings

FIG. **1** is a side view of an exemplary device according to the present invention;

FIG. **2** is a top view of the device of FIG. **1**;

FIG. **3** is a close-up first side view of the tip portion of the device of FIG. **1**;

FIG. **4** is a close-up second side view of the tip portion of the device of FIG. **1**;

FIG. **5** is a close-up top view of the tip portion of the device of FIG. **1** with jaw **16a** removed;

FIG. **6** is a cross-sectional view of the jaws **16a**, **16b** of the device of FIG. **1** taken along line **5-5** of FIG **5**;

FIG. **7** is a cross-sectional view of the jaws **16a**, **16b** of the device of FIG. **1** with tissue and fluid taken along line **5-5** of FIG **5**;

FIG. **8** is a cross-sectional view of an alternative embodiment of jaws **16a, 16b** of the device of FIG. **1** taken along line **5-5** of FIG **5**;

FIG. **9** is an exemplary block diagram showing one embodiment of a system of the invention with the device of FIG. **1**;

FIG. **10** is another cross-sectional view of the jaws **16a, 16b** of the device of FIG. **1** with tissue and fluid taken along line **5-5** of FIG **5**;

FIG. **11** is an exemplary graph that describes the relationship of load impedance (Z, in ohms) and generator output power (P, in watts), for an exemplary generator output of 75 watts in a bipolar mode;

FIG. **12** is a cross-sectional view of another alternative embodiment of jaws **16a, 16b** of the device of FIG. **1** taken along line **5-5** of FIG **5**;

FIG. **13** is a close-up top view of the alternative embodiment of jaws **16a, 16b** of FIG. **12** with jaw **16a** removed;

FIG. **14** is a cross-sectional view of another alternative embodiment of jaws **16a, 16b** of the device of FIG. **1** taken along line **5-5** of FIG **5**;

FIG. **15** is an exemplary graph that describes a relationship between RF power to tissue (P) versus flow rate of fluid (Q);

FIG. **16** is a cross-sectional view of another alternative embodiment of jaws **16a, 16b** of the device of FIG. **1** taken along line **5-5** of FIG **5**;

FIG. **17** is a cross-sectional view of another alternative embodiment of jaws **16a, 16b** of the device of FIG. **1** taken along line **5-5** of FIG **5**;

FIG. **18** is an assembled isometric view of another alternative embodiment of the tip portion and jaws **16a, 16b** of the device of FIG. **1**;

FIG. **19** is an exploded isometric view of the assembly of FIG. **18**;

FIG. **20** is a first side cross-sectional view of the tip portion of FIG. **18**;

FIG. **21** is a second side cross-sectional view of the tip portion of FIG. **18**;

FIG. **22** is an isometric view of another exemplary device according to the present invention;

FIG. **23** is a block diagram showing another embodiment of a system of the invention with a device of the present invention;

FIG. **24** is a block diagram of an electrical configuration for a generator and a device of the present invention without a hand switch;

FIG. **25** is a block diagram of an electrical configuration for a generator and a device of the present invention with a hand switch;

FIG. **26** is a block diagram of an electrical configuration for a generator, a device of the present invention with a hand switch, and an adaptor of the present invention therebetween;

FIG. **27** is a block diagram of another electrical configuration for a generator and a device of the present invention without a hand switch;

FIG. **28** is a block diagram of another electrical configuration for a generator and a device of the present invention with a hand switch;

FIG. **29** is a block diagram of another electrical configuration for a generator and a device of the present invention without a hand switch;

FIG. **30** is a block diagram of another electrical configuration for a generator, a device of the present invention without a hand switch, and an adaptor of the present invention therebetween; and

FIG. **31** is a block diagram of another electrical configuration for a generator, a device of the present invention with a hand switch, and an adaptor of the present invention therebetween.

Detailed Description

Throughout the present description, like reference numerals and letters indicate corresponding structure throughout the several views, and such corresponding structure need not be separately discussed. Furthermore, any particular feature(s) of a particular exemplary embodiment may be equally applied to any other exemplary embodiment(s) of this specification as suitable. In other words, features between the various exemplary embodiments described herein are interchangeable as suitable, and not exclusive. Also, from the specification, it should be clear that any use of the terms "distal" and "proximal" are made in reference to the user of the device, and not the patient.

An exemplary electrosurgical device according to the present invention will now be described in detail. The electrosurgical device may be used with the system of the invention to be described herein. However, it should be understood that the description of the combination is for purposes of illustrating the system of the invention only. Consequently, it should be understood that the electrosurgical device of the present invention can be used alone, or in conjunction with, the system of the invention. Conversely, it should be equally understood that the system of the present invention can be used with a wide variety of devices.

An exemplary electrosurgical device of the present invention, which may be used in conjunction with one or more aspects of the system of the present invention, is shown at reference character **10** in FIG. **1**. FIG. **1** shows a side view of device **10**, which is designed and configured to manipulate (e.g. grasp, coagulate and cut) tissue. Device **10** preferably comprises a tissue grasper, particularly forceps and more particularly endoscopic forceps as shown. When device **10** comprises

endoscopic forceps, preferably device **10** is configured to extend through a working channel of a trocar cannula.

As shown in FIG. **1**, device **10** preferably includes an intermediate portion, comprising a hollow shaft **12**, and a tip portion **14**. As shown, tip portion **14** preferably comprises two directly opposing, cooperating, relatively moveable jaws **16a**, **16b** connected and located adjacent the distal end **18** of the shaft **12**.

Also as shown in FIG. **1**, device **10** also preferably includes a collar **20** for rotating the entire shaft **12** and connecting a proximal handle **22** to the proximal end of the shaft **12** and an actuation lever **24** (preferably comprising a first-class lever) which when squeezed towards the pistol or hand grip portion **26** of the handle **22** in the direction of arrow **28** will close the opposing jaws **16a**, **16b** in a manner known in the art.

Continuing with FIG. **1**, device **10** also preferably includes a pair of opposing paddles **30** to activate a built-in cutting mechanism **32** (shown in FIG. **5**); a cable **34** extending from the butt of the grip portion **26** of handle **22** comprising two insulated wires **36**, **38** containing wire conductors **40**, **42** (shown in FIGS. **3** and **4**) connected and configured to deliver energy (e.g. RF power) to jaws **16a**, **16b**, preferably through the shaft **12** and handle **22**, and connectable to a source of energy (e.g. via plug connectors to plug clip receptacles **137a**, **137b** of the opposite terminals of a bipolar electrical generator **136** as shown in FIG. **9**); and a input fluid line **44** comprising a passage **46** (e.g. lumen) extending from the butt of the grip portion **26** of handle **22** that is connected and configured to deliver fluid **128** (also shown in FIG. **9**) via dividing branches to jaws **16a**, **16b**, also preferably through the shaft **12** and handle **22**, and connectable to a fluid source **130** (e.g. saline IV bag shown in FIG. **9**).

As shown in FIGS. **3** and **4**, jaws **16a**, **16b** are preferably connected to an actuator comprising rods **48** which move distally to close the jaws **16a**, **16b** with the movement of actuation lever **24** towards grip portion **26** of handle **22**, and proximally with the opening of the jaws **16a**, **16b** with the movement of actuation lever **24** away from grip portion **26** of handle **22**. More specifically, rods **48** preferably extend into moving pivot holes **50**, with the rotation for each moving pivot hole **50** configured around a hinge comprising a fixed pin **53** extending through a fixed pivot hole **52** of shaft **12** and aligning holes in the jaws **16a**, **16b**.

Before continuing with the description of jaws **16a**, **16b**, it should be understood that, as used herein, the longitudinal dimension is relative to the length of the jaws **16a**, **16b** and is directed proximally and distally, the lateral dimension is relative to the width of the jaws **16a**, **16b** and is directed laterally (outward) or

medially (inward), and the vertical dimension is relative to the height of the jaws **16a, 16b** and is directed by opening and closing relative to one another.

As best shown in FIG. **6**, jaws **16a, 16b** preferably comprise elongated, substantially rectangular, centrally located tissue support members **58a, 58b** which protrude from base portions **60a, 60b** towards one another. As shown, support members **58a, 58b** and base portions **60a, 60b** may comprise a unitarily formed single piece. However, in alternative embodiments, as shown in FIG. **16**, support members **58a, 58b** and base portions **60a, 60b** may comprise separately formed connected pieces.

As shown in FIG. **6**, support members **58a, 58b** provide anvils for directly opposing tissue grasping surfaces **62a, 62b**. As shown in FIGS. **3** and **4**, when the jaws **16a, 16b** are open the grasping surfaces **62a, 62b** converge proximally and diverge distally.

Grasping surfaces **62a, 62b** further comprise electrically insulative surfaces which are preferably provided by support members **58a, 58b** and base portions **60a, 60b** comprising electrically insulating materials. In this manner, support members **58a, 58b** and base portions **60a, 60b** may be electrically insulated relative to electrodes **64a, 66a, 64b, 66b** discussed in greater detail below.

In some embodiments, the electrically insulating material may comprise an electrically insulating polymer, either thermoplastic or thermoset, reinforced or unreinforced, filled or unfilled. Exemplary polymer materials include, but are not limited to, polyacetal (POM), polyamide (PA), polyamideimide (PAI), polyetheretherketone (PEEK), polyetherimide (PEI), polyethersulfone (PES), polyimide (PI), polyphenylenesulfide (PPS), polyphthalamide (PPA), polysulfone (PSO), polytetrafluoroethylene (PTFE) and syndiotactic polystyrene (SPS). More preferably, the electrically insulating polymer comprises either a liquid crystal polymer and, more particularly, an aromatic liquid crystal polyester which is reinforced with glass fiber, such as Vectra® A130 from Ticona, or Ultem® 10% glass filled polyetherimide from the General Electric Company. Exemplary reinforcement materials for polymers include, but are not limited to, glass fibers and boron fibers. Exemplary filler materials for polymers include mica, calcium carbonate and boron nitride. Reinforcement materials for the polymer material may be preferable for increased strength while filler materials may be preferable for increased heat resistance and/or thermal conductivity. Still other electrically insulating materials for support members **58a, 58b** and base portions **60a, 60b** may comprise electrically insulating ceramics such as boron nitride.

In order that heat may be transferred away from surfaces **62a, 62b** during use of device **10**, preferably the material for support members **58a, 58b** and base

portions **60a, 60b** has a thermal conductivity k_{tc} at 300°K (Kelvin) equal or greater than about 0.01 watt/cm°K. More preferably, the material for support members **58a, 58b** and base portions **60a, 60b** has a thermal conductivity k_{tc} at 300°K (Kelvin) equal or greater than about 0.16 watt/cm°K. Even more preferably, the material for support members **58a, 58b** and base portions **60a, 60b** has a thermal conductivity k_{tc} at 300°K (Kelvin) equal or greater than about 0.35 watt/cm°K.

In addition to grasping surfaces **62a, 62b** comprising electrically insulating surfaces, preferably grasping surfaces **62a, 62b** are substantially flat and provide for tissue removal there from. Furthermore, preferably grasping surfaces **62a, 62b** also comprise hydrophobic surfaces to reduce the presence of fluid (e.g. conductive fluid **128** from fluid source **130**; blood and other bodily fluids) on and between the grasping surfaces **62a, 62b**, particularly those portions which are unoccupied by tissue during treatment.

However, so that grasping surfaces **62a, 62b** don't become so smooth that tissue therebetween may slide out, preferably the surfaces **62a, 62b** are not highly polished smooth surfaces. In other words, preferably surfaces **62a, 62b** have a surface roughness or asperity of surface in the range between and including about 20 microns to 500 microns where 10 microns is indicative of a polished surface. More preferably, **62a, 62b** surfaces have a surface roughness in the range between and including about 25 microns to 250 microns. Furthermore, in various embodiments, surfaces **62a, 62b** may comprise textured surfaces (a surface which is not smooth, but rather includes a raised pattern on it), such as a stipple textured surfaces. Also, in various embodiments, surfaces **62a, 62b** may include serrations **67** (as shown in FIG. **17**).

In certain applications, it may be necessary to further increase the thermal conductivity of support members **58a, 58b** and base portions **60a, 60b** to better function as heat sinks to remove heat transferred to surfaces **62a, 62b** from tissue there between. In alternative embodiments as shown in FIG. **8**, jaws **16a, 16b** comprise an electrically insulative, thin (less than about 0.5 mm thick) coating **68** which provides grasping surfaces **62a, 62b** and which overlies support members **58a, 58b** and base portions **60a, 60b**, which comprise a material having a relatively higher thermal conductivity than the coating **68**. For example, the insulative coating **68** may comprise a polymer coating applied over an underlying metal. In such an instance, it may be desirable to make the polymer coating **68** as thin as possible to maximize heat transfer into the underlying structure. An exemplary electrically insulative coating **68** may comprise a fluorinated polymer, such as polytetrafluoroethylene (PTFE). Exemplary metals which may underlie the

electrically insulative coating are preferably non-corrosive, such as stainless steel, aluminum, titanium, silver, gold and platinum.

Preferably the material for support members **58a, 58b** and base portions **60a, 60b** underlying the coating **68** has a thermal conductivity k_{tc} at 300°K (Kelvin) equal or greater than about 0.1 watt/cm°K. More preferably, the material for support members **58a, 58b** and base portions **60a, 60b** underlying the coating **68** has a thermal conductivity k_{tc} at 300°K (Kelvin) equal or greater than about 1 watt/cm°K. Even more preferably, the material for support members **58a, 58b** and base portions **60a, 60b** underlying the coating **68** has a thermal conductivity k_{tc} at 300°K (Kelvin) equal or greater than about 2 watt/cm°K.

As shown in FIG. **8**, another structure which may be used to remove heat from support members **58a, 58b** and base portions **60a, 60b** comprises one or more heat pipes **63** containing a fluid **65** therein and connected to a heat exchanger as known in the art. Heat pipes **63** may be connected to a heat exchanger thermally isolated from the support members **58a, 58b** and base portions **60a, 60b** for removing heat from support members **58a, 58b** and base portions **60a, 60b**, or the heat pipe may be convectively cooled by fluid **128** provided to the jaws **16a, 16b**.

As best shown in FIGS. **3-4** and **6**, jaw **16a** may include two electrodes **64a, 66a** while jaw **16b** may include two directly opposing electrodes **64b, 66b**. Each electrode **64a, 66a, 64b, 66b** is connectable to the generator **136** (as shown in FIG. **9**), preferably by being electrically coupled via wire conductors **40, 42** of insulated wires **36, 38** which are ultimately electrically coupled to generator **136**. Electrodes **64a, 66a, 64b, 66b** preferably comprise a non-corrosive metal, such as stainless steel, aluminum, titanium, silver, gold or platinum.

As best shown in FIGS. **3** and **4**, preferably electrodes **64a, 66a, 64b, 66b** are orientated to extend along the length of the jaws **16a, 16b** from the proximal end portions **70a, 70b** to the distal end portions **72a, 72b** of grasping surfaces **62a, 62b**, preferably laterally outside the confines and borders of grasping surfaces **62a, 62b**. Each electrode **64a, 66a, 64b, 66b** is preferably configured to be substantially parallel to and equally spaced from support members **58a, 58b** and grasping surfaces **62a, 62b** along their respective lengths. However, in alternative embodiments, the electrodes **64a, 66a, 64b, 66b** may not be substantially parallel, for example, to compensate for a varying width of grasping surfaces **62a, 62b** or tissue thickness.

Preferably electrodes **64a, 64b** comprise electrical source electrodes while electrodes **66a, 66b** comprise counter electrodes. As shown in FIG. **6**, source electrodes **64a, 64b** are shown with the positive electrical sign (+) while counter electrodes **66a, 66b** are shown with the negative electrical sign (-). Thus, the source electrodes **64a, 64b** and counter electrodes **66a, 66b** have different electrical

potentials. Also as shown in FIG. **6**, each jaw **16a, 16b** may comprise one electrical source electrode and one electrical counter electrode, with the two electrodes on each of the jaws **16a, 16b** configured to have the same polarity with the directly opposing electrodes on the opposite jaw.

Given the above configuration, electrodes **64a, 66a, 64b, 66b** are configured such that electrical current flowing in the tissue between grasping surfaces **62a, 62b** will flow across (substantially parallel to) the grasping surfaces **62a, 62b**. With electrodes **64a, 66a, 64b, 66b** in such a configuration, four possible electrical paths are created between: (1) electrodes **64a** and **66a**; (2) electrodes **64a** and **66b**; (3) electrodes **64b** and **66b**; and (4) electrodes **64b** and **66a**.

The creation of certain of these electrical paths is denoted by electrical field lines **74** in FIG. **7**. It should be noted that the contour of electrical field lines **74** is exemplary. Furthermore, particularly outside grasping surfaces **62a, 62b**, it should be noted that the electrical field lines **74** are exemplary as to where electrical current is expected to flow, and not necessarily where the greatest current density is expected to reside.

Returning to FIG. **6**, it is to be understood that, within the scope of the invention, only one pair of electrodes is required for the invention (as shown in FIG. **17**). Furthermore, it is to be understood that, within the scope of the invention, where only one electrode pair is utilized, the electrodes do not have to be on the same jaw (as shown in FIG. **10**). In other words, the electrodes, while still configured outside of and separated from opposing edges of grasping surfaces **62a, 62b,** may be configured with one electrode on each jaw (e.g. diagonally arranged). Thus, a suitable electrode pair may comprise any pair of electrodes above (i.e. **64a** and **66a**; **64a** and **66b**; **64b** and **66b**; **64b** and **66a**) which create any one of the four electrical paths identified.

As indicated above, preferably grasping surfaces **62a, 62b** also comprise hydrophobic surfaces to reduce the presence of fluid on and between grasping surfaces **62a, 62b**, particularly portions which are unoccupied by tissue. Reducing the presence of fluid on unoccupied portions of surfaces **62a, 62b** is desirable to inhibit, and more preferably minimize or prevent, the formation of a conductive fluid shunt. In other words, if conductive fluid forms a bridge across the width of surfaces **62a, 62b**, and the bridge connects an electrode pair configured to create an electrical path (i.e. **64a** and **66a**; **64a** and **66b**; **64b** and **66b**; **64b** and **66a**), an electrical path through the conductive fluid bridge is created parallel to the electrical path through tissue. Consequently, a portion of the electrical energy intended to be provided to tissue is diverted through the conductive fluid bridge and bypasses the tissue. This loss of energy can increase the time required to treat tissue.

Other than surfaces **62a, 62b** comprising hydrophobic surfaces, in order to reduce the presence of fluid on and between the unoccupied portions of grasping surfaces **62a, 62b** of device **10**, preferably the contact angle θ of fluid droplets, particularly of fluid **128**, on grasping surfaces **62a, 62b** is about 30 degrees or greater after the droplet has stabilized from initial placement thereon. More preferably, the contact angle θ of fluid droplets, particularly of fluid **128**, on grasping surfaces **62a, 62b** is about 45 degrees or greater. More preferably, the contact angle θ of fluid droplets, particularly of fluid **128**, on grasping surfaces **62a, 62b** is about 60 degrees or greater. Even more preferably, the contact angle θ of fluid droplets, particularly of fluid **128**, on grasping surfaces **62a, 62b** is about 75 degrees or greater. Most preferably, the contact angle θ of fluid droplets, particularly of fluid **128**, on grasping surfaces **62a, 62b** is about 90 degrees or greater.

Contact angle, θ, is a quantitative measure of the wetting of a solid by a liquid. It is defined geometrically as the angle formed by a liquid at the three phase boundary where a liquid, gas and solid intersect. In terms of the thermodynamics of the materials involved, contact angle θ involves the interfacial free energies between the three phases given by the equation $\gamma_{LV} \cos \theta = \gamma_{SV} - \gamma_{SL}$ where γ_{LV}, γ_{SV} and γ_{SL} refer to the interfacial energies of the liquid/vapor, solid/vapor and solid/liquid interfaces, respectively. If the contact angle θ is less than 90 degrees the liquid is said to wet the solid. If the contact angle is greater than 90 degrees the liquid is non-wetting. A zero contact angle θ represents complete wetting.

For clarification, while it is known that the contact angle θ may be defined by the preceding equation, in reality contact angle θ is determined by a various models to an approximation. According to publication entitled "Surface Energy Calculations" (dated September 13, 2001) from First Ten Angstroms (465 Dinwiddie Street, Portsmouth, Virginia 23704), there are five models which are widely used to approximate contact angle θ and a number of others which have small followings. The five predominate models and their synonyms are: (1) Zisman critical wetting tension; (2) Girifalco, Good, Fowkes, Young combining rule; (3) Owens, Wendt geometric mean; (4) Wu harmonic mean; and (5) Lewis acid/base theory. Also according to the First Ten Angstroms publication, for well-known, well characterized surfaces, there can be a 25% difference in the answers provided for the contact angle θ by the models. Any one of the five predominate models above which calculates a contact angle θ recited by a particular embodiment of the invention should be considered as fulfilling the requirements of the embodiment, even if the remaining four models calculate a contact angle θ which does not fulfill the recitation of the embodiment.

As best shown in FIGS. 3-4 and 6, in certain embodiments, each electrode **64a, 66a, 64b, 66b** comprises an elongated structure extending longitudinally on jaws **16a, 16b**. As best shown in FIG. 6, electrodes **64a, 66a, 64b, 66b** preferably each comprise generally tubular structures having cylindrical outer surfaces **76a, 78a, 76b, 78b** with substantially uniform diameters. Preferably, electrodes **64a, 66a, 64b, 66b** have a cross-sectional dimension (e.g. diameter) in the range between and including about 0.1 mm to 4 mm and more preferably have a diameter in the range between and including about 1 mm to 2 mm.

As shown in FIGS. 3 and 4, in certain embodiments, electrodes **64a, 66a, 64b, 66b** have distal end wall portions **80a, 82a, 80b, 82b** comprising generally domed shapes. In this manner, the distal ends of electrodes **64a, 66a, 64b, 66b** preferably provide smooth, blunt contour outer surfaces which are devoid of sharp edges.

It should be understood that the structure providing electrodes **64a, 66a, 64b, 66b** need not wholly comprise an electrically conductive material. In other words, for example, only the tissue interacting/treating surfaces **76a, 78a, 76b, 78b** of electrodes **64a, 66a, 64b, 66b** need be electrically conductive. Thus, for example, the exemplary tubular structure for electrodes **64a, 66a, 64b, 66b** may comprise an electrically conductive coating, such as metal, overlying an electrically insulative material, such as a polymer or ceramic.

As best shown by FIG. 5, the surfaces **76a, 78a, 76b, 78b** of electrodes **64a, 66a, 64b, 66b** for treating tissue preferably terminate proximal to the distal end of a cutting mechanism **32** (where a cutting mechanism is employed), which preferably comprises a planar blade with a sharpened distal end. Cutting mechanism **32** is extendable from the distal end **18** of shaft **12** and travels on and along a center plane **CP** that is perpendicular to grasping surfaces **62a, 62b** (as shown in FIG. 6) and segments the jaws **16a, 16b** into opposing first and second sides (i.e. left-side portion and right-side portion), which are symmetrical in certain embodiments. Cutting mechanism **32** travels both longitudinally proximally and distally in an elongated travel slot **33a, 33b**. Cutting mechanism **32** is particularly used with endoscopic versions of device **10**. In this manner, device **10** is configured to treat tissue proximal to the distal end of the cutting mechanism **32** which reduces the possibility of cutting untreated or partially treated tissue with cutting mechanism **32** when activated.

In contrast to the contact angle θ of fluid droplets on device grasping surfaces **62a, 62b** most preferably being about 90 degrees or greater, preferably the contact angle θ of fluid droplets, particularly fluid **128**, on surfaces **76a, 78a, 76b, 78b** of electrodes **64a, 66a, 64b, 66b** is about 90 degrees or less after the droplet has

stabilized from initial placement thereon. More preferably, the contact angle θ of fluid droplets, particularly fluid **128**, on surfaces **76a, 78a, 76b, 78b** of electrodes **64a, 66a, 64b, 66b** is about 75 degrees or less. More preferably, the contact angle θ of fluid droplets, particularly fluid **128**, on surfaces **76a, 78a, 76b, 78b** of electrodes **64a, 66a, 64b, 66b** is about 60 degrees or less. Even more preferably, the contact angle θ of fluid droplets, particularly fluid **128**, on surfaces **76a, 78a, 76b, 78b** of electrodes **64a, 66a, 64b, 66b** is about 45 degrees or less. Most preferably, the contact angle θ of fluid droplets, particularly fluid **128**, on surfaces **76a, 78a, 76b, 78b** of electrodes **64a, 66a, 64b, 66b** is about 30 degrees or less.

Preferably fluid **128** (shown in FIGS. **7** and **9**) wets the surfaces **76a, 78a, 76b, 78b** of electrodes **64a, 66a, 64b, 66b** such that the fluid **128** forms a thin, continuous film coating at least partially thereon and does not form isolated rivulets or circular beads which freely run off the surfaces **76a, 78a, 76b, 78b** of electrodes **64a, 66a, 64b, 66b**.

As shown in FIG. **7**, each jaw **16a, 16b** preferably comprises at least one fluid flow passage and outlet configured to provide fluid **128** to surfaces **166a, 166b** of tissue **156** and/or surfaces **76a, 78a, 76b, 78b** of electrodes **64a, 66a, 64b, 66b**, and/or therebetween. To minimize complexity, preferably a portion of an electrode forms at least a portion of the fluid flow passage.

As best shown in FIGS. **3-4** and **6**, in certain embodiments, each electrode **64a, 66a, 64b, 66b** is hollow and comprises a rectilinear, longitudinally extending, cavity forming a central (primary) fluid flow passage **84a, 86a, 84b, 86b** for fluid **128**. To minimize complexity, each electrode **64a, 66a, 64b, 66b** may be formed from hypodermic tubing and the central flow passages **84a, 86a, 84b, 86b** comprise the lumens of the hypodermic tubing. Furthermore, as shown in FIG. **6**, the hypodermic tubing provides a cornerless electrode to distribute electrical energy to the tissue more uniformly and avoid concentrated edge effects typically encountered with the transmission of electrical energy through electrodes having sharp edges.

As best shown in FIGS. **3-4** and **5**, each central flow passage **84a, 86a, 84b, 86b** is preferably orientated to extend along the length of the jaws **16a, 16b** from the proximal end portions **70a, 70b** to the distal end portions **72a, 72b** of grasping surfaces **62a, 62b** of the jaws **16a, 16b**, preferably laterally outside grasping surfaces **62a, 62b**. Also, as shown, each central flow passage **84a, 86a, 84b, 86b** is preferably configured to extend along the length of the jaws **16a, 16b** coextensively with electrodes **64a, 66a, 64b, 66b**. Furthermore, as shown, each central flow passage **84a, 86a, 84b, 86b** is preferably configured to be substantially parallel to and equally spaced from support members **58a, 58b** and grasping surfaces **62a, 62b** along their respective lengths.

As shown in FIGS. 3 and 4, preferably each central flow passage **84a, 86a, 84b, 86b** has a central flow passage fluid entrance opening **88a, 90a, 88b, 90b** located near the proximal end **54** of jaws **16a, 16b**. Also as shown, each central flow passage **84a, 86a, 84b, 86b** is connectable to the fluid source **130** (shown in FIG. 9), preferably by being fluidly coupled with the passage **46** of flexible tube **44** which is ultimately fluidly coupled to fluid source **130**.

In addition to central flow passages **84a, 86a, 84b, 86b**, as best shown in FIG. 6, the flow passages also preferably comprise at least one rectilinear, radially directed, side (secondary) fluid flow passage **92a, 94a, 92b, 94b** which is fluidly coupled to each central flow passage **84a, 86a, 84b, 86b**. More preferably, as shown in FIGS. 3-6, each fluid flow passage preferably comprises a plurality of side flow passages **92a, 94a, 92b, 94b** which are defined and spaced preferably both longitudinally and circumferentially around electrodes **64a, 66a, 64b, 66b** and central flow passages **84a, 86a, 84b, 86b**. Also preferably, as shown the side flow passages **92a, 94a, 92b, 94b** are defined and spaced from the proximal end portions **70a, 70b** to the distal end portions **72a, 72b** of grasping surfaces **62a, 62b** of each jaw **16a, 16b**.

Also as shown, side flow passages **92a, 94a, 92b, 94b** preferably each have a cross-sectional dimension, more specifically diameter, and corresponding cross-sectional area, less than the portion of central flow passage **84a, 86a, 84b, 86b** from which fluid **128** is provided. Also as shown, the side flow passages **92a, 94a, 92b, 94b** extend through the cylindrical portion of the electrodes **64a, 66a, 64b, 66b** and are preferably formed substantially at a right angle (e.g. within about 10 degrees of a right angle) to the central flow passages **84a, 86a, 84b, 86b** both longitudinally and circumferentially. Also as shown, the side flow passages **92a, 94a, 92b, 94b** are preferably formed substantially at a right angle to the tissue interacting/treating cylindrical surfaces **76a, 78a, 76b, 78b** of electrodes **64a, 66a, 64b, 66b**.

Preferably, side flow passages **92a, 94a, 92b, 94b** extend from central flow passages **84a, 86a, 84b, 86b** to side flow passage fluid exit openings **96a, 98a, 96b, 98b** located on surfaces **76a, 78a, 76b, 78b**. More preferably, side flow passages **92a, 94a, 92b, 94b** and associated side flow passage fluid exit openings **96a, 98a, 96b, 98b** are defined and spaced both longitudinally and circumferentially around the surfaces **76a, 78a, 76b, 78b**, along the length of the jaws **16a, 16b** from the proximal end portions **70a, 70b** to the distal end portions **72a, 72b** of grasping surfaces **62a, 62b** of the jaws **16a, 16b**.

As shown in FIGS. 3-6, preferably the plurality of side flow passages **92a, 94a, 92b, 94b**, and corresponding side flow passage fluid exit openings **96a, 98a, 96b, 98b** are configured to form both longitudinal and circumferential straight rows,

and are preferably uniformly spaced relative to one another. Also preferably, the plurality of side flow passages **92a, 94a, 92b, 94b** are configured to distribute fluid flow exiting from side flow passage fluid exit openings **96a, 98a, 96b, 98b** substantially uniformly.

Preferably, side flow passages **92a, 94a, 92b, 94b** have a cross-sectional dimension (e.g. diameter) in the range between and including about 0.1 mm to 1 mm and more preferably have a diameter in the range between and including about 0.15 mm to 0.2 mm. As for central flow passages **84a, 86a, 84b, 86b**, preferably central fluid flow passages **84a, 86a, 84b, 86b** have a cross-sectional dimension (e.g. diameter) in the range between and including about 0.2 mm to 2 mm and more preferably have a diameter in the range between and including about 0.5 mm to 1 mm.

As shown in FIGS. 3 and 4, distal wall portions **80a, 82a, 80b, 82b** at least partially provide and define the distal ends of central flow passages **84a, 86a, 84b, 86b**, respectively. Also as shown, preferably wall portions **80a, 82a, 80b, 82b** completely provide and define the distal ends of central flow passages **84a, 86a, 84b, 86b** such that the distal ends of the central fluid flow passages **84a, 86a, 84b, 86b** preferably comprise blind ends. Consequently, the central flow passages **84a, 86a, 84b, 86b** preferably do not continue completely through electrodes **64a, 66a, 64b, 66b**. Rather, the distal ends of the central flow passages **84a, 86a, 84b, 86b** terminate within the confines of the electrodes **64a, 66a, 64b, 66b** and are closed by a structure, here wall portions **80a, 82a, 80b, 82b** forming the distal ends of central flow passages **84a, 86a, 84b, 86b**.

However, wall portions **80a, 82a, 80b, 82b** need not completely occlude and define the distal ends of central flow passages **84a, 86a, 84b, 86b**. In other words, rather than extending only partially through electrodes **64a, 66a, 64b, 66b**, central flow passages **84a, 86a, 84b, 86b** may extend completely through electrodes **64a, 66a, 64b, 66b** and have a distal end opening. However, in such an instance, a wall portions **80a, 82a, 80b, 82b** should substantially occlude and inhibit fluid **128** from exiting from the central flow passage distal end exit opening. With regards to this specification, occlusion of a central flow passage distal end exit opening and the corresponding inhibiting of flow from exiting from the central flow passage distal end exit opening should be considered substantial when the occlusion and corresponding inhibiting of flow results in increased flow from the side flow passage fluid exit openings **96a, 98a, 96b, 98b** of side flow passages **92a, 94a, 92b, 94b**. In other words, wall portions **80a, 82a, 80b, 82b** merely need to function as fluid flow diverters and redirect a portion of the fluid **128** coming in contact therewith from flowing parallel with the longitudinal axis of the central fluid flow passages **84a,**

86a, 84b, 86b to flowing radially from the longitudinal axis through side flow passages **92a, 94a, 92b, 94b**.

As shown, wall portions **80a, 82a, 80b, 82b** are preferably integral, and more preferably unitary, with the remainder of electrodes **64a, 66a, 64b, 66b**. Where electrodes **64a, 66a, 64b, 66b** are provided by hypodermic tubing, closure or occlusion of the central flow passages **84a, 86a, 84b, 86b** may be accomplished by welding or crimping (as best shown in FIGS. **20** and **21**) a previously open distal end of the hypodermic tubing. In alternative embodiments, wall portions **80a, 82a, 80b, 82b** may be provided by a separate plug inserted into the distal end portion of central flow passages **84a, 86a, 84b, 86b**. Also in alternative embodiments, wall portions **80a, 82a, 80b, 82b** may be provided by distal end portions **100a, 100b** of jaws **16a, 16b**.

Jaws **16a, 16b** preferably comprise at least one connector portion for attaching electrodes **64a, 66a, 64b, 66b** thereto. As shown in FIGS. **3** and **4**, the connector portions preferably comprise receptacles **102a, 104a, 102b, 104b** connected laterally adjacent to the support members **58a, 58b** and located at the distal end portions **100a, 100b** of jaws **16a, 16b**. As shown in FIGS. **3** and **4**, the connector portions for attaching electrodes **64a, 66a, 64b, 66b** to jaws **16a, 16b** are vertically adjacent base portions **60a, 60b** and protrude from base portions **60a, 60b** towards one another in the same manner as support members **58a, 58b**.

Preferably, receptacles **102a, 104a, 102b, 104b** are formed unitarily with support members **58a, 58b** as single pieces and provide a housing comprising cylindrical blind holes for containing distal end cylindrical portions **106a, 108a, 106b, 108b** of electrodes **64a, 66a, 64b, 66b**. The distal end cylindrical portions **106a, 108a, 106b, 108b** of the electrodes **64a, 66a, 64b, 66b** located in the receptacles **102a, 104a, 102b, 104b** preferably form an interference fit within the receptacles **102a, 104a, 102b, 104b** to inhibit removal therefrom.

Preferably jaws **16a, 16b** also comprise a second connector portion for attaching electrodes **64a, 66a, 64b, 66b** thereto. As shown in FIGS. **3** and **4**, the connector portions preferably comprise receptacles **110a, 112a, 110b, 112b** connected laterally adjacent to the support members **58a, 58b** and located at the proximal end portions **114a, 114b** of jaws **16a, 16b**.

Preferably, receptacles **110a, 112a, 110b, 112b** are also formed unitarily with support members **58a, 58b** as single pieces and provide a housing comprising cylindrical through holes for containing proximal end cylindrical portions **116a, 118a, 116b, 118b** of electrodes **64a, 66a, 64b, 66b**. The proximal end cylindrical portions **116a, 118a, 116b, 118b** of the electrodes **64a, 66a, 64b, 66b** located in the

receptacles **110a, 112a, 110b, 112b** preferably form an interference fit within the receptacles **110a, 112a, 110b, 112b** to inhibit removal therefrom.

In certain situations tissue laterally outside grasping surfaces **62a, 62b** may be compressed by a portion of the jaws **16a, 16b**, particularly electrodes **64a, 66a, 64b, 66b**. In order to concentrate a great majority of the electrical power converted to heat in the tissue located in the medial portion of grasping surfaces **62a, 62b** (equal to about the middle one-third of the width) preferably the tissue outside grasping surfaces **62a, 62b** will be compressed to a lesser extent (e.g. percentage) than the tissue between grasping surfaces **62a, 62b**. Consequently, as shown in FIG. **6**, preferably surfaces **76a, 78a, 76b, 78b** of electrodes **64a, 66a, 64b, 66b** are vertically recessed and, more particularly, stepped down relative to surfaces **62a, 62b** such that the minimum separation distance S_e between directly opposing electrode surfaces **76a, 76b** and **78a, 78b** is greater than the minimum separation distance S_s between grasping surfaces **62a, 62b**. As a result, tissue which may be partially compressed between surfaces **76a, 76b** and **78a, 78b**, for example, will be heated less than tissue in the medial portion of surfaces **62a, 62b** which is more fully compressed. However, as shown in FIG. **7**, surfaces **76a, 78a, 76b, 78b** should not be stepped down relative to surfaces **62a, 62b** such that electrical coupling is not maintained with surfaces **166a, 166b** of tissue **156** and fluid couplings **160** and **162** (discussed in greater detail below) are unable to couple the surfaces **76a, 78a, 76b, 78b** with surfaces **166a, 166b** of tissue **156**.

Continuing with FIG. **6**, surfaces **76a, 78a, 76b, 78b** of electrodes **64a, 66a, 64b, 66b** are preferably configured such that the portion of surfaces **76a, 78a, 76b, 78b** closest to grasping surfaces **62a, 62b** is remotely located and spatially separated from grasping surfaces **62a, 62b**. More specifically, as shown, the portion of surfaces **76a, 78a, 76b, 78b** closest grasping surfaces **62a, 62b** is remotely separated both laterally and vertically from grasping surfaces **62a, 62b**. Furthermore, as shown, preferably the portion of surfaces **76a, 78a, 76b, 78b** closest to grasping surfaces **62a, 62b** is remotely separated from grasping surfaces **62a, 62b** by air gaps **119** (which are ultimately occupied by fluid couplings **160** discussed below).

As shown in FIG. **6**, the air gaps **119** are defined by two sides relative to device **10**. More specifically, the air gaps **119** are defined by a portion of the surface of lateral side surfaces **121a, 121b** of support members **58a, 58b** and a portion of the surfaces **76a, 78a, 76b, 78b** of electrodes **64a, 66a, 64b, 66b**. Air gaps **119** preferably have a width (e.g. shortest distance between an electrode surface and an edge of a tissue grasping surface) greater than about 0.5 mm, and in the range between and including about 0.5 mm to 5.0 mm. More preferably, air gaps **119**

preferably have a width greater than about 1 mm, in the range between and including about 1 mm to 3.0 mm.

In the presence of tissue **156** as shown in FIG. **7**, the air gaps **119** may be further defined by a portion of the surfaces **166a, 166b** of tissue **156**. As shown, the portion of the surfaces **166a, 166b** of tissue **156** preferably extends between a separation point **123** from electrodes **64a, 66a, 64b, 66b** and edges **125a, 125b** to grasping surfaces **29a, 29b**. Among other things, these three sides help to shape fluid couplings **160** into the triangular shape described below.

Given that air gaps **119** are elongated in that they extend longitudinally along the length of surfaces **62a, 62b** and electrodes **64a, 66a, 64b, 66b**, the air gaps **119** also provide an open fluid flow channel or trough for fluid **128** from fluid source **130** to flow along the length of surfaces **62a, 62b** and electrode surfaces **76a, 78a, 76b, 78b**.

As shown in FIG. **6**, the outer perimeter edges **125a, 125b** to grasping surfaces **62a, 62b** of jaws **16a, 16b** comprise sharp edges. However, in other embodiments, as shown in FIG. **8**, edges **125a, 125b** may comprise bevel edges. Edges **125a, 125b** preferably comprise beveled edges rather than sharp edges to inhibit inadvertent cutting of tissue **156**. However, more importantly, beveled edges are configured to further concentrate a great majority of the electrical power converted to heat in the tissue located in the medial portion of grasping surfaces **62a, 62b**. In still other embodiments, as shown in FIG. **16**, edges **125a, 125b** may comprise a polymer, such as provided by a coating **127**, for example, of PTFE while grasping surfaces **62a, 62b** comprise a ceramic such as boron nitride.

As shown in FIGS. **3-6**, distal end portions **100a, 100b** of jaws **16a, 16b** preferably comprise a generally domed shape, and provide an obstruction (e.g. the structure forming receptacles **102a, 104a, 102b, 104b** for inhibiting fluid **128** from flowing around the distal end **56** of the jaws **16a, 16b** and forming a conductive fluid bridge which may form a shunt between certain electrode pairs having different polarities (e.g. **64a, 66a** and **64b, 66b**).

Similarly to distal end portions **100a, 100b**, proximal end portions **114a, 114b** of jaws **16a, 16b** also provide an obstruction (e.g. the structure forming receptacles **110a, 112a, 110b, 112b**) for inhibiting fluid **128** from flowing around the proximal end **54** of the jaws **16a, 16b** and forming a conductive fluid bridge which may form a shunt between certain electrode pairs having different polarities (e.g. **64a, 66a** and **64b, 66b**).

As shown in FIG. **6**, base portions **60a, 60b** preferably comprise a maximum lateral (width) dimension **d** equal to or less than the maximum lateral dimension of electrodes **64a, 66a, 64b, 66b**. In this manner, the electrical coupling of tissue to

electrodes **64a**, **66a**, **64b**, **66b** is less likely to be disrupted if tissue contacts base portions **60a**, **60b** during use of device **10**.

Continuing with FIG. **6**, preferably the contour of backside surfaces **120a**, **120b** of jaws **16a**, **16b** provides one or more obstructions which inhibits fluid **128** from flowing around the backside of the jaws **16a**, **16b** and forming a conductive fluid bridge which may form a shunt between certain electrode pairs having different polarities (e.g. **64a**, **66a** and **64b**, **66b**). As shown, the contour of the backside surfaces **120a**, **120b** preferably comprises one or more longitudinally extending protrusions **122a**, **122b** which provide drip edges **124a**, **124b** for fluid **128** to separate from device **10**. If a protrusion **122a**, **122b** is not utilized (possibly due to size constraints), the contour of the backside surfaces **120a**, **120b** may comprise one or more longitudinally extending recesses **126a**, **126b** which also provides drip edges **124a**, **124b** adjacent thereto for fluid **128** to separate from device **10**. In the above manner, conductive fluid **128** flowing medially around the backside of the jaws **16a**, **16b** is inhibited from forming a bridge across the backside surfaces **120a**, **120b** of the jaws **16a**, **16b** and may be redirected to flow along the length of the jaws **16a**, **16b**, either proximally or distally, until separation therefrom.

As indicated above, device **10** may be used as part of a system. FIG. **9** shows a block diagram of one exemplary embodiment of a system of the invention. As shown in FIG. **9**, fluid **128** is provided from a fluid source **130** through a fluid source output fluid line **132** which is acted on by a pump **134** that is connected to input fluid line **44** to electrosurgical device **10**.

In a preferred embodiment, the output fluid line **132** and the input fluid line **44** are flexible and are made from a polymer material, such as polyvinylchloride (PVC) or polyolefin (e.g. polypropylene, polyethylene). In another embodiment, the output fluid line **132** and the input fluid line **44** are preferably connected via a male and female mechanical fastener configuration **133**, preferably comprising a Luer-Lok® connection from Becton, Dickinson and Company.

Preferably, fluid **128** comprises a saline solution and, more preferably sterile, physiologic saline. It should be understood that where description herein references the use of saline as the fluid **128**, other electrically conductive fluids, as well as non-conductive fluids, can be used in accordance with the invention.

For example, in addition to the conductive fluid comprising physiologic saline (also known as "normal" saline, isotonic saline or 0.9 weight-volume percentage sodium chloride (NaCl) solution), the conductive fluid may comprise hypertonic saline solution, hypotonic saline solution, Ringers solution (a physiologic solution of distilled water containing specified amounts of sodium chloride, calcium chloride, and potassium chloride), lactated Ringer's solution (a crystalloid electrolyte

sterile solution of distilled water containing specified amounts of calcium chloride, potassium chloride, sodium chloride, and sodium lactate), Locke-Ringer's solution (a buffered isotonic solution of distilled water containing specified amounts of sodium chloride, potassium chloride, calcium chloride, sodium bicarbonate, magnesium chloride, and dextrose), or any other electrolyte solution. In other words, a solution that conducts electricity via an electrolyte, a substance (salt, acid or base) that dissociates into electrically charged ions when dissolved in a solvent, such as water, resulting solution comprising an ionic conductor.

In certain embodiments as discussed herein, hypertonic saline, saturated with NaCl to a concentration of about 15% (weight-volume percentage), may be preferred to physiologic saline to reduce the electrical resistivity of the saline from about 50 ohm-cm at 0.9% to about 5 ohm-cm at 15%. This ten-fold reduction in electrical resistivity of the conductive fluid will enhance the reduction in heating (both resistance heating and conduction heating) of tissue and the conductive fluid itself as shown herein.

While a conductive fluid is preferred, as will become more apparent with further reading of this specification, the fluid **128** may also comprise an electrically non-conductive fluid. The use of a non-conductive fluid is less preferred to that of a conductive fluid as the non-conductive fluid does not conduct electricity. However, the use of a non-conductive fluid still provides certain advantages over the use of a dry electrode including, for example, thermal cooling and reduced occurrence of tissue sticking to the electrodes of the device **10**. Therefore, it is also within the scope of the invention to include the use of a non-conducting fluid, such as, for example, deionized water or 1.5% glycine.

Returning to FIG. 9, energy to heat tissue is provided from an energy source, such as an electrical generator **136** which may provide alternating current, RF electrical energy at various rates (i.e. power) to electrodes **64a, 66a, 64b, 66b**. As to the frequency of the RF electrical energy, it is preferably provided within a frequency band (i.e. a continuous range of frequencies extending between two limiting frequencies) in the range between and including about 9 kHz (kilohertz) to 300 GHz (gigahertz). More preferably, the RF energy is provided within a frequency band in the range between and including about 50 kHz (kilohertz) to 50 MHz (megahertz). Even more preferably, the RF energy is provided within a frequency band in the range between and including about 200 kHz (kilohertz) to 2 MHz (megahertz). Most preferably, RF energy is provided within a frequency band in the range between and including about 400 kHz (kilohertz) to 600 kHz (kilohertz).

As shown, the system may be configured to first direct the RF power from the generator **136** via a cable **138** to a power measurement device **140** that measures the actual RF power provided from the generator **136**. In one exemplary embodiment, preferably the power measurement device **140** does not turn the RF power off or on, or alter the RF power in any way. Rather, a power switch **142** connected to the generator **136** is preferably provided by the generator manufacturer and is used to turn the generator **136** on and off.

The power switch **142** can comprise any switch to turn the power on and off, and is commonly provided in the form of a footswitch or other easily operated switch, such as a switch **142a** mounted on the electrosurgical device **10**. The power switch **142** or **142a** may also function as a manually activated device for increasing or decreasing the rate of energy provided from the surgical device **10**. Alternatively, internal circuitry and other components of the generator **136** may be used for automatically increasing or decreasing the rate of energy provided to the surgical device **10**. The particular form of switch **142a** is not important to device **10** and any time of suitable switch known in the art may be used.

As shown in FIG. **9**, in series after power measurement device **140**, cable **34** of device **10** is connected to power measurement device **140** to provide the RF power from generator **136** to the device **10**. Alternatively, in other embodiments, power measurement device **140** may be eliminated and cable **34** may be connected directly to generator **136**.

Power **P** is preferably measured before it reaches the electrosurgical device **10**. For the situation where capacitive and inductive effects are negligibly small, from Ohm's law, power **P**, or the rate of energy delivery (e.g. joules/sec), may be expressed by the product of current times voltage (i.e. I x V), the current squared times resistance (i.e. I^2 x R), or the voltage squared divided by the resistance (i.e. V^2/R); where the current **I** may be measured in amperes, the voltage **V** may be measured in volts, the electrical resistance **R** may be measured in ohms, and the power **P** may be measured in watts (joules/sec). Given that power **P** is a function of current **I**, voltage **V**, and resistance (impedance) **R** as indicated above, it should be understood, that a change in power **P** is reflective of a change in at least one of the input variables. Thus, one may alternatively measure changes in such input variables themselves, rather than power **P** directly, with such changes in the input variables mathematically corresponding to a changes in power **P** as indicated above. Furthermore, it should be understood that the terms "impedance" and "resistance" as used herein are used interchangeably given the capacitive and inductive effects are considered negligible.

Heating of the tissue is preferably performed by means of electrical resistance heating. In other words, increasing the temperature of the tissue as a result of electric current flow through the tissue, with the associated electrical energy being converted into thermal energy (i.e. heat) via accelerated movement of ions as a function of the tissue's electrical resistance. Resistance heating provides direct, instantaneous heating inside tissue due to the current flow through the tissue.

Heating of the tissue is also accomplished by thermal conduction heating. With conduction, tissue is heated by thermal energy flowing through tissue to adjacent tissue by virtue of gradients in temperature. The source of the conduction heating is ultimately from the resistance heating.

Once a steady-state condition has been achieved, and all temperatures everywhere in the vicinity of the electrodes and grasped tissue are not changing with time, it is a reasonable approximation to assume that all heat delivered to tissue by RF power is ultimately carried away by the convective cooling of the flowing fluid **128**. Thus, the flow of the fluid **128** not only physically surrounds the grasped tissue, but it also can be seen as a cooling blanket around the targeted tissue treatment site and also limits the maximum temperature of the fluid **128** heated by tissue by forcing the heated fluid to drip off the electrodes and jaws of the device as the fluid **128** is replenished.

In one exemplary embodiment, the system may comprise a flow rate controller **144**. Preferably, the flow rate controller **144** is configured to actively link and mathematically relate the power **P** and the flow rate **Q** of fluid **128** to one another. Preferably, the controller **144** receives an input related to the level of RF power being provided from the generator **136** (e.g. from power measurement device **140**), and adjusts the flow rate **Q** of the fluid **128** to device **10**, thereby adjusting the temperature (preferably within a predetermined range) of tissue, particularly outside the targeted tissue treatment site (i.e. outside surfaces **62a, 62b**).

In one embodiment, the flow rate controller **144** may receive an input signal **146** (e.g. from the power measurement device **140**) and calculate an appropriate mathematically predetermined fluid flow rate **Q** to achieve a predetermined tissue and/or fluid temperature. The flow rate controller may include a selection switch **148** that can be set to provide a safety factor (e.g. 10%, 20%, 30%) beyond the mathematically predetermined fluid flow rate **Q**. An output signal **150** from the flow rate controller **144** may then be sent to the pump **134** which is correlated to the predetermined flow rate **Q** of fluid **128**, and thereby provide an appropriate fluid flow rate **Q** which corresponds to the power **P** being provided by the generator **136**.

In another exemplary embodiment, elements of the system are physically included together in one electronic enclosure. One such embodiment is shown by

enclosure within the outline box **152** of FIG **9**. In the illustrated embodiment, the pump **134**, flow rate controller **144**, and power measurement device **140** are enclosed within an enclosure, and these elements are connected through electrical connections to allow signal **146** to pass from the power measurement device **140** to the flow rate controller **144**, and signal **150** to pass from the flow rate controller **144** to the pump **134**. Other elements of a system can also be included within one enclosure, depending upon such factors as the desired application of the system, and the requirements of the user.

In various embodiments, the flow rate controller **144** of FIG. **9** can be a simple "hard-wired" analog or digital device that requires no programming by the user or the manufacturer. The flow rate controller **144** can alternatively include a processor, with or without a storage medium, in which the flow rate **Q** of fluid **128** is performed by software, hardware, or a combination thereof. In another embodiment, the flow rate controller **144** can include semi-programmable hardware configured, for example, using a hardware descriptive language, such as Verilog. In another embodiment, the flow rate controller **144** of FIG. **9** is a computer, microprocessor-driven controller with software embedded.

In yet another embodiment, the flow rate controller **144** can include additional features, such as a delay mechanism, such as a timer, to automatically keep the flow of fluid **128** on for several seconds after the RF power is turned off to provide a post-coagulation cooling of the tissue or "quench," which can increase the strength of the tissue seal. Also, in another embodiment, the flow rate controller **144** can include a delay mechanism, such as a timer, to automatically turn on the flow of fluid **128** several seconds before the RF power is turned on to inhibit the possibility of undesirable effects as sticking, desiccation, smoke production and char formation.

In still another embodiment, the flow rate controller **144** can be used to turn the flow on and off in response to an electrical switch, such as **142a**, located in the handle **22**. This would automatically turn the flow on when the jaws were clamped on tissue, and turn the flow off when the jaws were unclamped from tissue. As the lever **24** is moved toward the grip **26** of the handle **22**, a normally-closed single pole, single-throw electrical switch (e.g. switch **142a**) could be activated, completing a circuit, either through the power measurement device **140** or an additional pair of wires that would exit the handle **22** of device **10** and continue directly to the controller **144**. Such a switch would function in a manner similar to that of the generator footswitch to turn the RF power on and off.

Instead of using an electrical switch as described above, a separate on-off flow switch **143** could be located in the handle **22** such that it would be normally closed when the device jaws were open, and little or no fluid **128** could flow from,

for example a fluid source such as a passive gravity-fed saline delivery system. As lever **24** is moved into a latched or use position, clamping the jaws on tissue in a use position, a simple mechanism (push-rod, cam, lever) would open the flow switch **143** and allow fluid **128** to flow. This would be one of the simplest forms of flow control, and would be useful to minimize wasteful dripping of fluid **128** when the device **10** is not being used, as well as to minimize the amount of fluid **128** that would have to be suctioned out of the patient at a later time.

Also in another embodiment, the flow rate controller **144** can include a low level flow standby mechanism, such as a valve, which continues the flow of fluid **128** at a standby flow level (which prevents the flow rate from going to zero when the RF power is turned off) below the surgical flow level ordinarily encountered during use of device **10**.

The pump **134** can be any suitable pump used in surgical procedures to provide saline or other fluid **128** at a desired flow rate **Q**. Preferably, the pump **134** comprises a peristaltic pump. With a rotary peristaltic pump, typically fluid **128** is conveyed within the confines of fluid line **132** by waves of contraction placed externally on the line which are produced mechanically, typically by rotating rollers which squeeze flexible tubing against a support intermittently. Alternatively, with a linear peristaltic pump, typically a fluid **128** is conveyed within the confines of a flexible tube by waves of contraction placed externally on the tube which are produced mechanically, typically by a series of compression fingers or pads which squeeze the flexible tubing against a support sequentially. Peristaltic pumps are generally preferred for use as the electro-mechanical force mechanism (e.g. rollers driven by electric motor) does not make contact the fluid **128**, thus reducing the likelihood of inadvertent contamination.

Alternatively, pump **134** can be a "syringe pump", with a built-in fluid supply. With such a pump, typically a filled syringe is located on an electro-mechanical force mechanism (e.g. ram driven by electric motor) which acts on the plunger of the syringe to force delivery of the fluid **128** contained therein. Alternatively, the syringe pump may comprise a double-acting syringe pump with two syringes such that they can draw saline from a reservoir (e.g. of fluid source **130**), either simultaneously or intermittently. With a double acting syringe pump, the pumping mechanism is generally capable of both infusion and withdrawal. Typically, while fluid **128** is being expelled from one syringe, the other syringe is receiving fluid **128** therein from a separate reservoir. In this manner, the delivery of fluid **128** remains continuous and uninterrupted as the syringes function in series. Alternatively, it should be understood that a multiple syringe pump with two syringes, or any number of syringes, may be used in accordance with the invention.

In various embodiments, fluid **128**, such as conductive fluid, can also be provided from an intravenous (IV) bag full of saline (e.g. of fluid source **130**) that flows under the force of gravity. In such a manner, the fluid **128** may flow directly to device **10**, or first to the pump **134** located there between. In other embodiments, fluid **128** from a fluid source **130**, such as an IV bag, can be provided through a flow rate controller **144** which directly acts on controlling the flow of fluid **128**, rather than indirectly by means of pump **134**. Such a flow rate controller **144** may provide a predetermined flow rate **Q** by adjusting the cross sectional area of a flow orifice (e.g. lumen of fluid line such as **44** or **132**) while also sensing the flow rate **Q** with a sensor such as an optical drop counter. Furthermore, fluid **128** from a fluid source **130**, such as an IV bag, an be provided through automatically or manually adjusting flow rate controller **144**, such as a roller clamp (which also adjusts the cross sectional area of a flow orifice such as lumen of fluid line **44** or **132**) and is adjusted manually by, for example, the user of device **10** in response to their visual observation that the fluid rate **Q** needs adjustment.

Similar pumps can be used in connection with the invention, and the illustrated embodiments are exemplary only. The precise configuration of the pump **134** is not critical to the invention. For example, pump **134** may include other types of infusion and withdrawal pumps. Furthermore, pump **134** may comprise pumps which may be categorized as piston pumps, rotary vane pumps (e.g. axial impeller, centrifugal impeller), cartridge pumps and diaphragm pumps. In some embodiments, the pump **134** can be substituted with any type of flow controller, such as a manual roller clamp used in conjunction with an IV bag, or combined with the flow controller to allow the user to control the flow rate of conductive fluid to the device. Alternatively, a valve configuration can be substituted for pump **134**.

In various embodiments, other configurations of the system can be used with device **10**, and the illustrated embodiments are exemplary only. For example, the fluid source **130**, pump **134**, generator **136**, power measurement device **140** or flow rate controller **144**, or any other components of the system not expressly recited above, may comprise a portion of the device **10**. For example, in one exemplary embodiment the fluid source **130** may comprise a compartment of the device **10** which contains fluid **128**, as indicated at reference character **130a**. In another exemplary embodiment, the compartment may be detachably connected to device **10**, such as a canister which may be attached via threaded engagement with the device **10**. In yet another exemplary embodiment, the compartment may be configured to hold a pre-filled cartridge of fluid **128**, rather than the fluid directly.

Also for example, with regards to alternatives for the generator **136**, an energy source, such as a direct current (DC) battery used in conjunction with

inverter circuitry and a transformer to produce alternating current at a particular frequency, may comprise a portion of device **10**, as indicated at reference character **136a**. In one embodiment the battery element of the energy source may comprise a rechargeable battery. In yet another exemplary embodiment, the battery element may be detachably connected to device **10**, such as for recharging.

Turning to FIG. **7**, upon being connected to generator **136** and fluid source **130**, fluid **128** is expelled from side flow passage fluid exit openings **96a, 98a, 96b, 98b**. Fluid **128** expelled from the side flow passage fluid exit openings **96a, 98a, 96b, 98b** preferably forms a thin film coating on surfaces **76a, 78a, 76b, 78b** of electrodes **64a, 66a, 64b, 66b**. Excess fluid **128** may flow partially around to the backside surfaces **120a, 120b** and form a droplet **154** which subsequently falls and separates from device **10**, preferably from drip edges **124a, 124b**. Fluid **128** preferably is inhibited from locating on surfaces **62a, 62b** as already described herein.

As shown in FIG. **7**, when device **10** is introduced to tissue **156**, typically a surgeon will grasp a small amount of tissue **156**, shown here as a vessel with a lumen **158**, and compress the tissue **156** between the grasping surfaces **62a, 62b** of the jaws **16a, 16b**. Where the tissue includes a lumen **158**, such as the lumen of a blood vessel, the lumen will generally become occluded. Substantially simultaneously with the surgeon's manipulation of the tissue **156**, fluid **128** is continuously being expelled from the side flow passage fluid exit openings **96a, 98a, 96b, 98b**.

Fluid **128** expelled from the side flow passage flow exit openings **96a, 98a, 96b, 98b** couples tissue **156** and electrodes **64a, 66a, 64b, 66b**. As shown in FIG. **7**, fluid couplings **160, 162, 164** comprise discrete, localized webs, and more specifically triangular shaped webs. Fluid couplings **160, 162, 164** provide localized wells of fluid **128** which enhance the electrical coupling of tissue **156** and electrodes **64a, 66a, 64b, 66b** and remove heat generated in tissue **156** by convection. Furthermore, as discussed in greater detail below, couplings **160, 162, 164** provide a diversion there through for at least a portion of the electrical current flowing in tissue **156** outside grasping surfaces **62a, 62b**, whereby the amount of electrical energy available to be converted into heat in tissue **156** outside grasping surfaces **62a, 62b** may be correspondingly reduced. Additionally, couplings **160, 162, 164** provide a lubricant which lubricates the interface between surfaces **76a, 78a, 76b, 78b** of electrodes **64a, 66a, 64b, 66b** and surfaces **166a, 166b** of tissue **156** which inhibits sticking between electrodes **64a, 66a, 64b, 66b** and tissue **156** electrically coupled therewith.

Continuing with FIG. 7, as shown the fluid couplings **160**, **162**, **164** are laterally outside grasping surfaces **62a**, **62b** of the jaws **16a**, **16b**. Turning to fluid couplings **160** specifically, as shown they are laterally positioned between a portion of surfaces **76a**, **78a**, **76b**, **78b** of electrodes **64a**, **66a**, **64b**, **66b** and grasping surfaces **62a**, **62b** of the jaws **16a**, **16b** along outer perimeter edges **125a**, **125b**. Given their location, in addition to the benefits of electrical coupling, fluid couplings **160** remove heat from and cool the portion of tissue **156** laterally adjacent grasping surfaces **62a**, **62b** and also cool support members **58a**, **58b** along side surfaces **121a**, **121b** thereof.

As shown in FIG. 7, in order to provide fluid **128** at fluid couplings **160**, preferably a portion of the flow of fluid **128** is provided from certain of the side fluid flow passages **92a**, **94a**, **92b**, **94b** configured to direct fluid **128** to that portion of tissue **156** that is laterally adjacent grasping surfaces **62a**, **62b**.

Turning fluid couplings **162**, as shown in FIG. 7, they are positioned laterally relative to surfaces **76a**, **78a**, **76b**, **78b** of electrodes **64a**, **66a**, **64b**, **66b**. Given their location, in addition to the benefits of electrical coupling, fluid couplings **162** remove heat and cool the portion of tissue **156** laterally adjacent electrodes **64a**, **66a**, **64b**, **66b**. As shown in FIG. 7, in order to provide fluid **128** at fluid couplings **162**, preferably a portion of the flow of fluid **128** is provided from certain of the side fluid flow passages **92a**, **94a**, **92b**, **94b** configured to direct fluid **128** to that portion of tissue **156** that is laterally adjacent electrodes **64a**, **66a**, **64b**, **66b**.

Turning to fluid couplings **164**, unlike fluid couplings **160** and **162**, fluid couplings **164** are not configured to cool tissue **156**. Rather, fluid couplings **164** are configured to remove heat and cool support members **58a**, **58b** and base portions **60a**, **60b** of jaws **16a**, **16b**. As shown in FIG. 7, in order to provide fluid **128** at fluid couplings **164**, preferably a portion of the flow of fluid **128** is provided from certain of the side fluid flow passages **92a**, **94a**, **92b**, **94b** configured to direct fluid **128** to support members **58a**, **58b** and base portions **60a**, **60b** of jaws **16a**, **16b**.

Surfaces **166a**, **166b** of tissue **156** are often uneven or undulated with microscopic peaks and valleys. Without fluid **128**, the area of electrical coupling of tissue **156** to the surfaces **76a**, **78a**, **76b**, **78b** of electrodes **64a**, **66a**, **64b**, **66b** can be limited to the isolated peaks in the tissue surfaces **166a**, **166b**. In this situation, upon the application of RF energy to tissue **156**, the electrical coupling area of surfaces **166a**, **166b**, by virtue of being limited to the tissue peaks, results in corresponding increase in current density through the peaks which has the ability to desiccate and char the tissue **156**. Conversely, fluid **128** enters and occupies the previously unoccupied valleys and gaps **167** (as shown in FIG. 8) between tissue surfaces **166a**, **166b** and the surfaces **76a**, **78a**, **76b**, **78b** of electrodes **64a**, **66a**,

64b, 66b and enhances the electrical coupling of the tissue surfaces **166a, 166b** to the surfaces **76a, 78a, 76b, 78b** of electrodes **64a, 66a, 64b, 66b.**

Furthermore, the intimacy of electrical coupling between surfaces **166a, 166b** of tissue **156** and the surfaces **76a, 78a, 76b, 78b** of electrodes **64a, 66a, 64b, 66b** often decreases as the tissue shrinks away from surfaces **76a, 78a, 76b, 78b** and/or desiccates during tissue treatment. Conversely, fluid **128** provides a mechanism to offset losses in electrical coupling due to tissue shrinkage and/or desiccation by entering and occupying any gaps **167** (as shown in FIG. **8**) which have developed between surfaces **166a, 166b** of tissue **156** and the surfaces **76a, 78a, 76b, 78b** of electrodes **64a, 66a, 64b, 66b** during treatment.

Once the jaws **16a, 16b** are closed to a use position, RF power is then provided to the tissue **156.** RF power is provided at the tissue surface **166a, 166b** and below the tissue surface **166a, 166b** into the tissue **156** directly from electrodes **64a, 66a, 64b, 66b,** as well as through the fluid couplings **160** and **162** to a targeted tissue treatment site, here between grasping surfaces **62a, 62b,** thereby heating the tissue **156** to coagulate, shrink, weld or otherwise treat the tissue **156.**

If desired, after treating the tissue **156** between the jaws **16a, 16b,** the jaws **16a, 16b** can be held clamped together and cutting mechanism **32** can be actuated to cut the tissue **156.** As shown in FIG. **5,** cutting mechanism **32** preferably comprises a cutting blade with a sharpened distal end. Preferably cutting mechanism **32** is actuated by rotating paddles **30** distally to longitudinally extend the blade distally and thereafter rotating the paddles **30** proximally to longitudinally retract the cutting blade proximally.

In order to reduce tissue treatment time, lateral thermal spread and ensuing necrosis of tissue **156** laterally outside grasping surfaces **62a, 62b,** particularly tissue **156** laterally adjacent grasping surfaces **62a, 62b,** adjacent the electrodes **64a, 66a, 64b, 66b** and there in between, it is desirable to concentrate the energy to the tissue **156** between grasping surfaces **62a, 62b** of device **10** as shown below as part of the present invention. Before continuing, however, it should be noted that the examples below should only be considered to an order of magnitude approximation for explanatory purposes.

Electrical resistance $\mathbf{R_e}$ to the passage of RF current can be described by equation (1) below:

$$R_e = \rho_e L/A \quad (1)$$

where:

R_e = electrical resistance (ohms);
ρ_e = electrical resistivity (ohm-cm);
L = length (cm); and
A = area (cm^2).

In determining the electrical resistance of tissue R_{et} located between surfaces **62a, 62b** of device **10**, the length of tissue **L** is represented by the width across surfaces **62a, 62b** of jaws **16a, 16b**. The area **A** of the tissue is represented by a longitudinal dimension of surfaces **62a, 62b** and the thickness of tissue between surfaces **62a, 62b**. In other words, with reference to FIGS. **5** and **10** for dimensions **a, b** and **c**, the electrical resistance of tissue R_{et} located between surfaces **62a, 62b** using equation (1) is expressed as:

$$R_{et\,(\text{between grasping surfaces})} = \rho_{et} b/ac \tag{2}$$

By way of example, where the tissue **156** located between surfaces **62a, 62b** of device **10** has a dimension **a** of 0.025 cm, a dimension **b** of 0.3 cm, a dimension **c** of 3 cm and an electrical resistivity of the tissue ρ_{et} of 200 ohm-cm before treatment, the electrical resistance of the tissue R_{et} between surfaces **62a, 62b** of device **10** is about 800 ohms.

Conversely, for tissue **156** adjacent electrodes **64a, 66a, 64b, 66b**, equation (1) is expressed as:

$$R_{et\,(\text{adjacent the electrodes})} = \rho_{et} a/bc \tag{3}$$

Note that the area **A** of tissue **156** is now measured by the product of (b)(c). For tissue **156** adjacent electrodes **64a, 66a, 64b, 66b**, dimension **b** comprises the portion of the circumference of the electrodes **64a, 66a, 64b, 66b** electrically coupled to tissue **156**. Thus, as shown in FIG. **10**, dimension **b** can be approximated by about one-quarter of the circumference of electrodes **64a, 66a, 64b, 66b**. Consequently, where the diameter of electrodes **64a, 66a, 64b, 66b** is 0.15 cm, dimension **b** is about 0.1 cm for each electrode. Next, when dimension **c** is held constant (i.e. 3 cm), area **A** for each electrode **64a, 66a, 64b, 66b** is about 0.3 cm^2.

In the case of four electrodes with the electrical potential and positioning such as electrodes **64a, 64b** and **66a, 66b**, the electrical resistance of the tissue R_{et} adjacent electrodes **64a, 64b** and **66a, 66b** could be considered in parallel. However, in order to assume a worse case scenario, as well as simply the system, the

existence of only two electrodes (e.g. **64a, 66b**) will be assumed in continuing with the calculations herein.

Turning to dimension **a**, as shown in FIG. **10** electrodes **64a, 66b** are recessed relative to surfaces **62a, 62b**. Dimension **a** relative to electrodes **64a, 66b** can be somewhat arbitrarily estimated as being about twice dimension **a** between surfaces **62a, 62b.** Thus, using a dimension **a** of 0.05 cm, and keeping the electrical resistivity of the tissue ρ_{et} constant at 200 ohm-cm, the electrical resistance of the tissue $\mathbf{R_{et}}$ adjacent the electrodes **64a, 66b** is about 33 ohms. Thus, the above illustrates that the electrical resistance of the tissue $\mathbf{R_{et}}$ adjacent electrodes **64a, 66b** can be substantially lower than the electrical resistance of the tissue $\mathbf{R_{et}}$ between surfaces **62a, 62b.**

The total electrical resistance $\mathbf{R_{eTotal}}$ encountered in an electrical circuit for resistors in series can be approximated by adding the electrical resistance of each resistor in the circuit. Thus, for the example above, the total electrical resistance $\mathbf{R_{eTotal}}$ may be approximated as 866 ohms. Continuing with the above, assuming a power **P** of 35 watts and a total electrical resistance $\mathbf{R_{eTotal}}$ is 866 ohms, from Ohm's Law the current **I** is about 0.2 amps. In turn, also from Ohm's Law. the amount of the power **P** converted to heat in the tissue **156** located between surfaces **62a, 62b** of device **10** is about 32 watts while the power **P** converted into heat in the tissue **156** adjacent electrodes **64a, 66b** is about 3 watts. Stated another way, about 90% of the power is converted to heat in the resistance of the tissue **156** located between surfaces **62a, 62b** of device **10.**

Once the current **I** flowing through tissue **156** is known, the current density in tissue **156** may also be calculated. Current density is a vector quantity whose magnitude is the ratio of the magnitude of current **I** flowing through a substance to the cross-sectional area **A** perpendicular to the current direction of flow and whose direction points in the direction of the current flow. Current density is commonly expressed in amperes per square centimeter (i.e. amps/cm^2).

In light of the above definition, the current density in tissue **156** between surfaces **62a, 62b** of device **10** when using an area **A** of 0.075 cm^2 (i.e. dimension **a** of 0.025 cm and dimension **c** of 3 cm) as above is about 2.7 amps/cm^2. Conversely, the current density in tissue **156** adjacent electrodes **64a, 66b** when using an area **A** of 0.3 cm^2 as above is about 0.6 amps/cm^2. Thus, the current density in tissue **156** between surfaces **62a, 62b** of device **10** is on a magnitude of 4 times greater than the current density in tissue **156** adjacent electrodes **64a, 66a, 64b, 66b** for the preceding example.

In certain instances, use of device **10** may result in a load impedance outside the working range of a general-purpose generator **136**. For example, the schematic

graph of FIG. **11** shows the general output curve of a typical general-purpose generator, with the output power changing as load (tissue plus cables) impedance **Z** changes. Load impedance **Z** (in ohms) is represented on the X-axis, and generator output power **P** (in watts) is represented on the Y-axis. In the illustrated embodiment, the electrosurgical power (RF) is set to 75 watts in a bipolar mode.

As shown in FIG. **11**, the power **P** will remain constant as it was set as long as the impedance **Z** stays between two cut-offs, low and high, of impedance, that is, for example, between 50 ohms and 300 ohms in the illustrated embodiment. Below load impedance **Z** of 50 ohms, the power **P** will decrease, as shown by the low impedance ramp **168**. Above load impedance **Z** of 300 ohms, the power **P** will decrease, as shown by the high impedance ramp **170**. This change in output is invisible to the user of the generator and not evident when the generator is in use, such as in an operating room.

As shown by the exemplary calculations above, the high impedance cut-off where power **P** begins to decrease as shown by high impedance ramp **170** may be exceeded with use of device **10** and quite possibly be completely outside the working range of generator **136**. Consequently, as shown in FIG. **9**, it may be necessary to provide an impedance transformer **172** in a series circuit configuration between electrodes **64a**, **66a**, **64b**, **66b** of device **10** and the power output of generator **136**. Consequently, the impedance transformer **172** may be provided with device **10**, the generator **136** or any of the wire connectors (e.g. cable **34**) connecting device **10** and generator **136**. Impedance transformer **172** is configured to match the load impedance provided to generator **136** such that it is within the working range of the generator **136** and, more preferably in the working range between the low and high cut-offs.

As already described herein, an exemplary electrical resistivity of the tissue ρ_{et} is about 200 ohm-cm. Also as already described herein, for saline the electrical resistivity of the fluid ρ_{ef} is about 50 ohm-cm for physiologic saline and about 5 ohm-cm for hypertonic saline. Thus, the electrical resistivity of the tissue ρ_{et} for the present example is about four times to forty times greater than the electrical resistivity of the fluid ρ_{ef}. Consequently, assuming all else equal, electrical current **I** will flow more predominately through the conductive fluid **24** rather than through tissue **32**. The position of fluid couplings **160** is configured for this and exploits it.

As electrical current flows in the tissue **156** between surfaces **62a**, **62b** and exits from between surfaces **62a**, **62b**, it will seek a path to the counter electrode comprising the least electrical resistance $\mathbf{R_e}$. As already discussed herein, among other things, electrical resistance $\mathbf{R_e}$ is a function of electrical resistivity ρ_e and length **L** of the resistor. In the case of physiologic saline, the electrical resistivity of

the conductive fluid ρ_{ef} making up fluid couplings **160** is one-fourth the electrical resistivity of the tissue ρ_{et}. Furthermore, as shown in FIG. 7, the shortest distance for the electrical current **I** to travel to the counter electrode upon exiting from between surfaces **62a, 62b** is through fluid couplings **160**. An exemplary distance between the edges **125a, 126b** to surfaces **62a, 62b** and the closest portion of an electrode surface **76a, 76b, 78a, 78b** thereto is in the range between and including about 0.5 mm to 5.0 mm. More preferably, the distance between the edges **125a, 126b** to surfaces **62a, 62b** and the closest portion of an electrode surface **76a, 76b, 78a, 78b** is in the range between and including about 1 mm to 3.0 mm.

Consequently, electrosurgical device **10** and the system is configured to provide a diversion for (and preferably divert at least a portion of) electrical current, upon exiting from between grasping surfaces **62a, 62b**, to flow at least partially through conductive fluid **128** before reaching the counter electrode. In other words, couplings **160** and **162** provide a diversion there through for at least a portion of the electrical current flowing in tissue **156** outside grasping surfaces **62a, 62b**, whereby the amount of electrical energy available to be converted into heat in tissue **156** outside grasping surfaces **62a, 62b** may be correspondingly reduced.

Similar to the counter electrode side of the electrical path, as electrical current flows from the source electrodes and enters between surfaces **62a, 62b** it will also seek a path to the counter electrode comprising the least electrical resistance $\mathbf{R_e}$. Consequently, in addition to the above, device **10** and the system are also configured to provide a diversion for (and preferably divert at least a portion of) at least a portion of the electrical current, upon leaving the source electrode, at least partially through conductive fluid **128** before entering between grasping surfaces **62a, 62b**.

In light of the above, it may be desirable to increase the size (i.e. volume and area) of the fluid coupling between tissue **156** and the electrodes **64a, 66a, 64b, 66b**. More specifically, preferably the jaws **16a, 16b** are configured such that tissue **156** is inhibited from direct contact with the electrodes **64a, 66a, 64b, 66b**. Referring to FIG. **12** and **13**, a stand-off **174**, here a separator which holds two bodies separate from one another preferably at a predetermined distance, inhibits the tissue **156** from direct contact with surfaces **76a, 78a, 76b, 78b** of electrodes **64a, 66a, 64b, 66b**.

As shown, stand-off **174** preferably comprises a coil, preferably comprising electrically insulated surfaces, superimposed (overlying) and wrapped around the electrode surfaces **76a, 78a, 76b, 78b**, thus providing a helical flow channel **177** between bordering windings of the coil. As a result, fluid couplings **160** and **162** merge in a new fluid coupling shown at **176**. Fluid coupling **176**, by virtue of its increased size, provides an even greater diversion than fluid coupling **160** for at least a portion of the electrical current flowing in tissue **156** outside grasping surfaces

62a, 62b and, consequently, further reduces the amount of electrical energy available to be converted into heat in tissue **156** outside grasping surfaces **62a, 62b**.

Preferably the electrically insulative surfaces of the coil are provided by the coil being formed of an electrically insulative material, such as a polymer. For assembly, preferably each electrode **64a, 66a, 64b, 66b** is passed through the center longitudinal aperture of a coil, with the coil wrapped around and extending along the length of the surfaces **76a, 78a, 76b, 78b** of electrodes **64a, 66a, 64b, 66b** between the distal and proximal connector portions of jaws **16a, 16b** which connect the electrodes **64a, 66a, 64b, 66b** to the jaws **16a, 16b**.

In yet another embodiment, the stand-off may comprise a material pervious to the passage of fluid **128** therethrough. As shown in FIG. **14**, stand-off **175** may comprise a porous structure which includes a plurality of tortuous and interconnected fluid flow passages which provide and distribute fluid **128** to tissue **156**.

Similar to stand-off **174**, preferably stand-off **175** comprises a electrically insulative material, such as a polymer or ceramic, superimposed over the electrode surfaces **76a, 78a, 76b, 78b**. With an electrically insulative porous structure, RF energy is provided to tissue **156** through the electrically conductive fluid **128** contained within the plurality of interconnected tortuous pathways rather than the porous material itself. A porous polymer structure may be provided by a cellular solid comprising interconnected voids which define the tortuous and interconnected passages. For example, the porous polymer structure may comprise a polymer foam at least partially comprising an open cellular structure. Furthermore, in certain embodiments, the stand-off **175** may comprise a compressible, resilient structure, such as provided by a flexible or semi-rigid polymer foam. In this manner, the stand-off **175** can deform around tissue **156** to provide better electrical and fluid coupling therewith.

In certain embodiments, the electrodes **64a, 66a, 64b, 66b** may also comprise a material pervious to the passage of fluid **128** therethrough, such as a porous metal. The discrete, linear side flow passages **92a, 94a, 92b, 94b** may be either supplemented with or replaced by a plurality of tortuous, interconnected pathways formed in the porous material which, among other things, provide porous electrode surfaces **76a, 78a, 76b, 78b** which more evenly distribute fluid flow and provide fluid **128** to tissue **156**.

Preferably the porous materials provide for the wicking (i.e. drawing in of fluid by capillary action or capillarity) of the fluid **128** into the pores of the porous material. In order to promote wicking of the fluid **128** into the pores of the porous material, preferably the porous material, and in particular the surface of the tortuous

pathways, is hydrophilic. The porous material may be hydrophilic with or without post treating (e.g. plasma surface treatment such as hypercleaning, etching or micro-roughening, plasma surface modification of the molecular structure, surface chemical activation or crosslinking), or made hydrophilic by a coating provided thereto, such as a surfactant.

As described herein, in order that heat may be transferred away from surfaces **62a, 62b** during use of device **10**, preferably the material for support members **58a, 58b** (particularly the medial portion of support members **58a, 58b** adjacent surfaces **62a, 62b**) and base portions **60a, 60b** have a high thermal conductivity. As shown above, given that the vast amount of the power provided to tissue **156** is converted to heat in the tissue **156** between surfaces **62a, 62b** of device **10**, it may be necessary to configure support members **58a, 58b** and bases **60a, 60b** such that surfaces **62a, 62b** do not overheat. However, support members **58a, 58b** and bases **60a, 60b** should be also configured such that surfaces **62a, 62b** do not overcool. Preferably, during a typical use of device **10**, surfaces **62a, 62b** should remain in the temperature range between and including about 75 °C to 120 °C. More preferably, during use of device **10**, surfaces **62a, 62b** should remain in the temperature range between and including about 75 °C to 100 °C. Stated another way, surfaces **62a, 62b** should be hot enough to shrink collagen in the range between and including about 1 second to 10 seconds after RF activation.

As shown in FIG. **11**, RF power to tissue can vary even though the generator **136** has been "set" or "fixed" to a particular wattage. FIG. **15** shows an exemplary schematic graph that describes one relationship between the flow rate **Q** of fluid **128** (Y-axis in cc/min.) versus RF power **P** to tissue **156** (X-axis in watts). More precisely, as shown in FIG. **15**, the relationship between the rate of fluid flow **Q** and RF power **P** may be expressed as a direct, linear relationship, when a steady-state condition has been achieved (temperature not changing with time).

Based on a simple, one-dimensional, steady-state, lumped parameter model of the heat transfer and a predetermined peak tissue temperature, the flow rate **Q** of fluid **128** corresponding to the peak tissue temperature can be determined. The RF electrical power **P** that is converted into heat can be defined as:

$$P = \rho_m c_\rho Q_l \Delta T \tag{4}$$

where P = the RF electrical power that is converted into heat. The term $[\rho_m c_\rho Q_l \Delta T]$ in equation (4) is heat used to warm up the flow of fluid **128** to peak temperature (without boiling the fluid), where:

ρ_m = Density of the fluid (approximately 1.0 gm/cm^3 for physiologic saline);

c_ρ = Specific heat of fluid (approximately 4.1 watt-sec/gm-°C for physiologic saline);

Q_l = Flow rate of the fluid that is heated (cm^3/sec); and

ΔT = Temperature rise of the fluid. The difference in temperature between the peak fluid temperature and the initial (input) fluid temperature. The inlet fluid temperature is typically at ambient temperature or about 20 °C for a hospital operating room.

Assuming that the peak fluid temperature is the same as the peak tissue temperature at steady state, the flow rate for a predetermined peak fluid temperature (provided the temperature is at or below boiling of the fluid) can be determined by solving equation (4) for Q_l:

$$Q_l = [P]/\rho_m c_\rho \Delta T \qquad (5)$$

This equation defines the lines shown in FIG. **15** with a slope given by $1/(\rho_m c_p \Delta T)$. Assuming an inlet temperature of 20 °C, FIG. **15** shows several lines for different outlet temperatures of 45, 50, 60 and 100 °C.

Outside of surfaces **62a**, **62b** it is desirable to provide a tissue temperature which inhibits tissue necrosis. The onset of tissue necrosis will generally occur at about 60 °C with an exposure time of about 0.02 seconds. As temperature decreases, the time for tissue necrosis increases. For a tissue temperature of about 45 °C, exposure time increases to about 15 minutes. Thus, an exemplary targeted steady state temperature is about 50 °C.

Worse case, assuming all the power to tissue (i.e. here 35 watts) has to be removed by fluid **128** after the jaws **16a**, **16b** and fluid **128** have reached a targeted steady state temperature of 50°C, the calculated flow rate **Q** is [35]/(1)(4.1)(50-20) = 0.28 cc/sec or about 17 cc/min.

It should be understood that the flow rate **Q** above is merely exemplary. An exemplary range of flow rates for device **10** is from about 0.01 cc/min. to about 100 cc/min.

In light of the above, an exemplary control strategy which can be employed for the device **10** is to provide a flow rate **Q** of fluid **128** to inhibit necrosis of tissue **156** outside surfaces **62a**, **62b** which may be subject to necrosis by the portion of the total power **P** provided to tissue **156** outside surfaces **62a**, **62b**.

In order to determine when a predetermined temperature of the fluid **128** has been achieved (e.g., when the fluid reaches, for example, 50 °C), a thermochromic material (a material that changes color as it is heated or cooled), such as a thermochromic dye (e.g., leuco dye), may be added to the fluid. The dye can be formulated to provide a first predetermined color to the fluid at temperatures below a predetermined temperature, such as 50 °C, then, upon heating above 50 °C, the dye provides a second color, such as clear, thus turning the fluid clear (i.e. no color or reduction in color). This color change may be gradual, incremental, or instant. Thus, a change in the color of the fluid, from a first color to a second color (or lack thereof) provides a visual indication to the user of the electrosurgical device **5** as to when a predetermined fluid temperature has been achieved. Thermochromic dyes are available, for example, from Color Change Corporation, 1740 Cortland Court, Unit A, Addison, IL 60101.

In some embodiments, it can be desirable to control the temperature of the fluid **128** before it is released from the device **10**. In one embodiment, a heat exchanger is provided for the outgoing fluid flow to either heat or chill fluid **128**. The heat exchanger may be provided as part of device **10** or as part of another part of the system, such as within the enclosure **152**. Cooling the fluid **128** to a predetermined temperature, typically below room temperature, further inhibits thermal damage to tissue outside surfaces **62a, 62b**. More specifically, the use of chilled saline (i.e. below room temperature of about 20 °C and of any salt concentration) will inhibit tissue damage outside surfaces **62a, 62b** due to heat conduction. Flowing fluid **128** will absorb the heat from higher temperature tissue, dilute it with the cooler fluid **128** and remove it from the device **10**. Chilling and convective cooling should not significantly affect the amount of resistance heating except by slightly increasing the electrical resistivity for saline and chilled tissue. Chilling and convective cooling with the fluid **128** will simply reduce the peak temperatures that are created in the tissue outside surfaces **62a, 62b**.

In other embodiments, as shown in FIG. **16**, electrodes **64a, 66a, 64b, 66b** may be located at least partially directly beneath surfaces **62a, 62b**. Consequently, with such a configuration, heat transfer from support members **58a, 58b** and surfaces **62a, 62b** may be further increased. As shown, support members **58a, 58b**, particularly the portion underlying surfaces **62a, 62b**, are convection cooled by flowing fluid **128** provided from side flow passages **92a, 94a, 92b, 94b** of electrodes **64a, 66a, 64b, 66b**. Furthermore, the support members **62a, 62b** are also cooled via conduction of heat to the portions of electrodes **64a, 66a, 64b, 66b** in direct contact therewith. This heat is then transferred via conduction through electrodes **64a, 66a,**

64b, **66b** to flowing fluid **124** contained within central fluid flow passage **84a**, **86a**, **84b**, **86b** where it is carried away through side flow passages **92a**, **94a**, **92b**, **94b**.

Preferably device **10** is provided with a means to inform the use of the device when tissue between surfaces **62a**, **62b** has been sufficiently coagulated. As known in the art, with the application of RF power through tissue its impedance changes. As shown by Bergdahl, the electrical impedance of tissue initially decreases (to an impedance value below its initial untreated impedance value) and then subsequently increases as the tissue desiccates and coagulates. (Bergdahl, J. Neurosurg., Vol. 75, July 1991, pages 148-151). Correspondingly, in a constant voltage situation and by virtue of Ohm's law, the electrical current through the tissue initially increases (as tissue impedance decreases) and then decreases (as tissue impedance increases). Thus, the electrical current in the tissue is inversely proportional to the impedance.

However, prior art electrosurgical devices such as device **10** do not indicate the tissue impedance, or provide any visual or audible feedback as to the state of the tissue being treated at the targeted tissue treatment site. In a small number of instances, ammeters have been known to be located on generators, but due to relative location, for example in a hospital operating room, are not easily usable. Often the generator is removed from the patient and electrosurgical device, and not viewable by the user of the electrosurgical device without looking away from the surgical procedure. Consequently, clinical judgment and operator training are required to minimize or prevent incomplete coagulation or charring and sticking from overheating. If an under treated vessel is transected or cut, it may bleed or worse leak, often after the surgical incision is closed.

An advancement of the art would be to provide direct information when coagulation or other tissue treatment is completed, preferably such that the surgeon or other user of the electrosurgical device would be informed of the completion of tissue treatment while still looking towards the surgical procedure/patient and viewing the indicator within the their vision, either direct or indirect (peripheral) vision. Such would be particularly useful for laparoscopic surgery, particularly if the information was provided to the user of the device while viewing the peritoneal cavity.

As shown in FIGS. **1** and **9**, in order for the operator or other user of device **10** to gauge the level of treatment for tissue **156** between surfaces **62a**, **62b**, device **10** may be provided with a tissue treatment indicator **184**. Preferably the tissue treatment indicator **184** provides the user of device **10** with a visual output related to the level of treatment for tissue **156** between surfaces **62a**, **62b**. In one embodiment, the visual indicator preferably comprises a lighting device (e.g. incandescent bulb,

halogen bulb, neon bulb). In another embodiment, the visual indicator preferably comprises a thermochromic device.

As shown in FIG. 9, for example, the present invention may use an incandescent bulb or thermochromic strip wired in parallel circuit configuration with a power feed line (e.g. wire conductor **40** of insulated wire **36** of cable **34**) providing power to electrodes **64a, 66a, 64b, 66b** of device **10** from generator **136**. Consequently, the tissue treatment indicator **184,** here comprising an incandescent bulb or thermochromic strip, may be provided with device **10** (as shown), the generator **136** or any of the wire connectors (e.g. cable **34**) connecting device **10** and generator **136.**

More specifically, as shown in FIG. 9, the incandescent bulb or thermochromic strip is preferably wired in parallel circuit with a short section of wire conductor **40** (e.g. between about 1 cm and 60 cm of insulated wire **36** of cable **34**) within the confines of device **10** and mounted on device **10**, such as on handle **22** or preferably the tip portion **14** (as shown in FIG. 1). Preferably the indicator **184** is mounted to the tip portion **14** of device **10** such that when the tip portion **14** is inserted into the peritoneal cavity, or other cavity, the indicator **184** is visible within the confines of the peritoneal cavity by a surgeon using a laproscopic viewing scope or camera as known in the art.

During use of device **10**, the brightness and change in brightness of the indicator **184** during tissue coagulation can be used to indicate the level of coagulation and consequent coaptation of a vessel and tissue structure. More specifically, as the tissue impedance decreases initially, the indicator will increase in brightness (with increasing current) and thereafter decrease in brightness (with decreasing current) as the tissue impedance increases.

As shown in FIG. 11, the power **P** from generator **136** will remain constant as long as the impedance **Z** stays between a low impedance cut-off **168** and a high impedance cut-off **170**. As indicated above, transformer **172** is configured to match the load impedance provided to generator **136** such that it is within the working range of the generator **136** and, more preferably in the working range between the low impedance cut-off **168** and high impedance cut-off **170**.

Upon the application of device **10** to tissue, generally impedance will initially reside within the generator's working range between the low impedance cut-off **168** and high impedance cut-off **170**. Before tissue is treated in any significant manner, the indicator **184** will provide a first brightness level which is representative of a first impedance level.

For a period thereafter, the tissue impedance decreases. From Ohm's law, the change in impedance (here decrease) over a constant power **P** output from

generator **136** will result in a change in the current **I** (here increase) of the circuit. As the current increases, the brightness of the indicator **184** will correspondingly increase to a second brightness level which is representative of a second impedance level.

After reaching a minimum tissue impedance, the tissue impedance will change direction and begin to increase with tissue coagulation and desiccation. Here, the change in impedance (here increase) over a constant power **P** output from generator **136** will result in a change in the current **I** (here decrease) of the circuit. As the current decreases, the brightness of the indicator **184** will correspondingly decrease to a third brightness level which is representative of a third impedance level.

Thus from the above configuration, one would see current changes mirroring the tissue impedance changes. If the bulb (e.g. a tungsten filament type #47 or equivalent) were placed across a 1-foot segment of the power cable, the lamp brightness would provide visual indication of current. The lamp will glow brightly when device **10** is activated and the electrodes are in good contact with the tissue. Subsequently, there will be a marked decrease in brightness or dimming of the lighted bulb as coagulation advances and is completed.

The jaw configurations described above may be particularly useful for use through a 12 mm or greater diameter trocar cannula. In still other embodiments, the jaws may be configured to use through a 3 mm, 5 mm, 10 mm or greater diameter trocar cannula. As shown in FIG. **17**, in order to reduce size and complexity, the two electrodes from jaw **16a** have been eliminated (i.e. **64a**, **66a**). Furthermore, as shown, preferably the two remaining electrodes, here **64b**, **66b**, are located on the same jaw **16b**. Furthermore, the cutting mechanism **32** and the base **60a** have also been eliminated. Also as shown, jaw **16a** is configured substantially asymmetrical to jaw **16b** and has a much flatter profile. In this manner, jaws **16a**, **16b** may function as tissue dissectors. In other words, while jaws **16a**, **16b** are in the closed position and without tissue there between, they are wedged into tissue, preferably between adjacent tissue planes. Thereafter, the jaws **16a**, **16b** may be slowly opened and, due to the separation forces placed on the tissue at the distal end **56** of the jaws **16a**, **16b**, the tissue will dissect.

FIGS. **18-21** show another embodiment of the present invention with the medial portion of the backside surfaces **120a**, **120b** of jaws **16a**, **16b** comprising a substantially flat surface as opposed to the arcuate surface of previous embodiments.

Thus far the device **10** has been described relative to use with an endoscopic grasper, and in particular endoscopic forceps. In still other embodiments, as shown

in FIG. 22, the present tissue grasper of the present invention may comprise an open surgery grasper and more particularly open surgery forceps.

Returning to transformer 172, when transformer 172 is provided as part of device 10, such as with cable 34 as shown in FIG. 9, cable 34 of device 10 may ordinarily comprise two insulated wires 36, 38 connectable to generator 136 via two banana (male) plug connectors 35a, 35b (as best shown in FIG. 1), connecting to (female) plug receptacles 137a, 137b of the generator 136. As shown in FIG. 1, the banana plug connectors 35a, 35b are each assembled with wires 36, 38 within individual plug housings 43a, 43b which are not connected relative to one another and may be referred to as "loose leads". Consequently, in this embodiment, the banana plug connectors 35a, 35b are independently movable relative to one another. In this manner, plug connectors 35a, 35b are not fixed in a predetermined position relative to one another and thus may be arranged to connect to a variety generators 136 which may have receptacle connectors 137a, 137b with different patterns and placement. Exemplary electrical configurations established between banana plug connectors 35a, 35b of device 10 and banana plug receptacle connectors 137a, 137b of generator 136 are further illustrated in FIGS. 23 and 24. From the above, it should be understood that the use of plug connectors and receptacle connectors, is merely exemplary, and that other types of mating connector configurations may be employed.

In other embodiments, transformer 172 may be assembled with wires 36, 38 and plug connectors 35a, 35b in a single, common housing similar to the housing 43 shown in FIG. 25. In contrast to the previous embodiment, in this embodiment the plug connectors 35a, 35b are held in a fixed, predetermined position relative to one another. In this manner, the plug connectors 35a, 35b can be tailored to fit only those generators 136 with receptacle connectors 137a, 137b positioned to coincide or match up with the predetermined positions of the plug connectors 35a, 35b.

Plug connectors 35a, 35b are provided in a single common housing 43 to better and more easily direct the plug connectors 35a, 35b to their predetermined targeted plug receptacle connectors 137a, 137b by virtue of being held in a fixed, predetermined position relative to one another by plug housing 43 such that they can only coincide with receptacle connectors 137a, 137b, respectively.

As shown in FIG. 25, the wiring within plug housing 43 of device 10 may be configured such that hand switch 142a may be electrically coupled to the bipolar mode hand switching circuitry of generator 136. More specifically, as shown hand switch 142a of device 10 is electrically coupled to generator 136 upon the insertion of bipolar hand switch plug connector 35c of device 10 into bipolar hand switch

receptacle connector **137c** of generator **136**. In other embodiments, the hand switch **142a** may be eliminated and foot switch **142** of generator **136** may be used alone.

In still other embodiments, transformer **172** may be provided as part of an electrical adaptor **186** connected in series between device **10** and generator **136** as shown in FIG. **26**. In this embodiment, preferably the adaptor **186** includes its own receptacle connectors **188a, 188b** on one side which are configured to receive plug connectors **35a, 35b** of device **10**, and on the opposing side has its own plug connectors **190a, 190b** which are configured to connect to receptacle connectors **137a, 137b** of generator **136**.

As shown in FIG. **26**, adaptor **186** may also be configured to accommodate device **10** with hand switch **142a**. In addition to the various connectors identified above, adaptor **186** has its own bipolar hand switch receptacle connector **188c** on one side configured to mate with the bipolar hand switch plug connector **35c** of device **10**, and on the opposing side has its own bipolar hand switch plug connector **190c** configured to connect to bipolar hand switch receptacle connector **137c** of generator **136**. Finally, in order to establish the remaining link between the hand switch circuitry and the bipolar power output, the adaptor **186** has a hand switch plug connector **188d** configured to mate with hand switch receptacle connector **35d** of device **10**.

As shown in FIG. **26**, device **10** now includes four connectors (i.e. **35a, 35b, 35c, 35d**) when adaptor **186** is used rather than just the three connectors (i.e. **35a, 35b, 35c**) associated with the embodiment of FIG. **25**. Connector **35d** is added to provide a connection, when mated with connector **188d** of adaptor **186**, to plug connector **190a** which bypasses transformer **172**. This is required as the hand switch circuitry of generator **136** typically utilizes direct current (DC) rather than the alternating current (AC) associated with the power circuitry. Consequently, since continuous DC will not cross between the primary coil **173** and secondary coil **175** (shown in FIG. **23**), of transformer **172**, this fourth connection is required.

Turning to the specifics of transformer **172**, preferably the transformer **172** comprises primary and secondary coils **173, 175** comprising #18 magnet wire wound on a toroidal shaped, magnetic core **179**. Primary coil **173** receives power from the generator **136** while secondary coil **175** receives the power from the primary coil **173** and delivers it to the load. More preferably the core **179** comprises a ferromagnetic core and even more preferably a ferrite core. Preferably the ferrite has an amplitude permeability in the range of 500 μ to 5,000 μ and more preferably of about 2,000 μ. More preferably, the ferrite comprises ferrite material no. 77.

For a perfect transformer, that is, a transformer with a coefficient of coupling (k) equal to 1, the impedances can be described as follows:

$$Z_p = Z_s(N_p/N_s)^2 \qquad (6)$$

where:

Z_p = Impedance looking into the primary coil from the power source;
Z_s = Impedance of load connected to secondary coil;
N_p = Number of turns (windings) for primary coil; and
N_s = Number of turns (windings) for secondary coil

As indicated above, as shown in exemplary FIG. **11**, the power **P** in bipolar mode will remain constant as it was set as long as the impedance **Z** stays between two cut-offs, low and high, of impedance, that is, for example, between 50 ohms and 300 ohms in the illustrated embodiment. Below load impedance **Z** of 50 ohms, the power **P** will decrease, as shown by the low impedance ramp **168**. Above load impedance **Z** of 300 ohms, the power **P** will decrease, as shown by the high impedance ramp **170**.

In light of the above, in bipolar mode the primary impedance $\mathbf{Z_p}$ should be no greater than 300 ohms. As for secondary impedance $\mathbf{Z_s}$, as shown above, secondary impedance $\mathbf{Z_s}$ may be on the order of 900 ohms. Based a primary impedance $\mathbf{Z_p}$ = 300 ohms and a secondary impedance $\mathbf{Z_s}$ = 900 ohms, the transformer **172** should be a step-up transformer with a turns ratio, N_p/N_s of 1:1.7.

However, it has been found that for general-purpose generators **136**, the high impedance cut-off in bipolar mode may occur substantially below 300 ohms. It has been found, that for some general-purpose generators **136**, the high impedance cut-off may occur at only about 100 ohms. Based a primary impedance $\mathbf{Z_p}$ = 100 ohms and a secondary impedance $\mathbf{Z_s}$ = 900 ohms, the transformer **172** should be a step-up transformer with a turns ratio, N_p/N_s of 1:3.

It should also be recognized that the above calculations for N_p/N_s are predicated on an electrical resistivity of the tissue $\boldsymbol{\rho}_{\mathbf{et}}$ of 200 ohm-cm. However, in certain instances the electrical resistivity of the tissue $\boldsymbol{\rho}_{\mathbf{et}}$ can be on the order of about 2500 ohm-cm, for example, for fat tissue. In this situation the electrical resistance of the tissue $\mathbf{R_{et}}$ may be on the order of 10,000 ohms. Based a primary impedance $\mathbf{Z_p}$ = 100 ohms and a secondary impedance $\mathbf{Z_s}$ = 10,000 ohms, the transformer **172** should be a step-up transformer with a turns ratio, N_p/N_s of 1:10. When the primary impedance $\mathbf{Z_p}$ is increased back to 300 ohms for a generator with this high impedance cut-off, the transformer **172** should be a step-up transformer with a turns ratio, N_p/N_s of 1:5.8.

More probable than above, the electrical resistivity of the tissue ρ_{et} will be on the order of about 1200 ohm-cm, in which case the electrical resistance of the tissue $\mathbf{R_{et}}$ may be on the order of 4,800 ohms. Based a primary impedance $\mathbf{Z_p}$ = 100 ohms and a secondary impedance $\mathbf{Z_s}$ = 4,800 ohms, the transformer **172** should be a step-up transformer with a turns ratio, N_p/N_s of 1:7. When the primary impedance $\mathbf{Z_p}$ is increased back to 300 ohms for a generator with this high impedance cut-off, the transformer **172** should be a step-up transformer with a turns ratio, N_p/N_s of 1:4.

Returning to FIG. **11**, as indicated above the high impedance cut-off for bipolar mode at 75 watts occurs at about 300 ohms. Based on Ohm's law, for 75 watts and 300 ohms, the voltage before power begins to drop in bipolar mode is about 150 volts RMS (root mean squared). However, with use of transformer **172**, the voltage associated with the first and second coils are also changed along with the impedances. With the transformer above, secondary voltage may be described as follows:

$$V_s = V_p(N_s/N_p) \tag{7}$$

where:

V_s = Secondary voltage;
V_p = Primary voltage;
N_p = Number of turns (windings) for primary coil; and
N_s = Number of turns (windings) for secondary coil

With a primary voltage $\mathbf{V_p}$ = 150 volts RMS as calculated above, and a turns ratio, N_p/N_s of 1:1.7, the secondary voltage $\mathbf{V_s}$ is equal to 255 volts RMS. However, with a primary voltage $\mathbf{V_p}$ = 150 volts RMS, and a turns ratio, N_p/N_s of 1:5.8, the secondary voltage $\mathbf{V_s}$ can increase to 870 volts RMS.

In certain instances, it may be desirable to decrease the secondary voltage $\mathbf{V_s}$ back to its "pre-transformer" level, in other words, for example, 150 volts RMS. As shown in FIG. **27**, device **10** may be provided with an autotransformer **192**, which, among other things, is a transformer comprising a single coil as opposed to two coils. As shown in FIG. **27**, autotransformer **192** comprises a single coil **196** which is wound around core **194** to produce, what is electrically, a primary and a secondary coil. This is different from the conventional two-coil transformer **172**, which has the primary and secondary coils **173**, **175** electrically insulated from each other, but magnetically linked by a common core. The autotransformer's "coils" are both electrically and magnetically interconnected.

The coil **196** is tapped at a location along a portion of its length by tap **198**, which results in a voltage change which corresponds to the location of the tap **198**. As shown in FIG. **27**, the AC voltage from the source (generator **136**) is connected across many more turns on the single coil **196** than is the output connections for the electrodes. The coil **196** has a specific number of volts per turn. By tapping up so many turns, a lower voltage can be obtained. More specifically, the voltage change is determined by the turns ratio N_p/N_s corresponding to the location of the tap **198**.

Equally important in the use of autotransformer **192** is that, as shown in FIG. **27**, the primary and secondary share a common connection. Since there is a direct connection between primary and secondary, the autotransformer **192** provides no isolation. Consequently, there is substantially no resistance, if any, between primary and secondary coils. This is the primary advantage associated with using autotransformer **192**. The voltage between the primary and secondary may be substantially decreased, with no substantial change in the resistance between the coils. Thus, the resistance between the coils stays substantially the same, and the higher impedance cut-off created with use of transformer **172** is maintained even though autotransformer **192** has been added to the device **10** and the system.

For autotransformer **192**, the secondary voltage $\mathbf{V_s}$ associated with transformer **172** now comprises the primary voltage $\mathbf{V_p}$ for autotransformer **192.** As a result, using the formula above, to bring a primary voltage $\mathbf{V_p}$ of 870 volts RMS of the autotransformer **192** back to a secondary voltage $\mathbf{V_s}$ to 150 volts RMS, a step-down autotransformer is used with a turns ratio N_p/N_s of 5.8:1. As shown, the autotransformer **192** has a turns ratio N_p/N_s which is exactly inverse to the turns ratio N_p/N_s associated with transformer **172**.

It should be understood that, while the voltage may be theoretically returned to its "pretransformer" level with the use of autotransformer **192,** Ohm's Law, in addition to electrode geometry, tissue resistivity, device design, device method of use and system configuration, may impose additional practical limitations. For example, for a bipolar power of 50 watts, and an electrical resistance of the tissue $\mathbf{R_{et}}$ on the order of 4,800 ohms, Ohm's Law provides that the practical lower limit on voltage $\mathbf{V_s}$ is about 490 RMS to get an acceptable current flow. While this is greater than the 150 volts RMS which normally may be observed with known "dry" bipolar devices, the devices of the present invention may facilitate the use of higher voltages without adverse consequences due to, among other things, the presence of a fluid provided at the tissue treatment site. Thus, it should be understood, that the turns ratio associated with the respective transformers is merely exemplary, and that the turns ratio N_p/N_s associated with the autotransformer **192** merely be greater than the turns ratio N_p/N_s associated with transformer **172** to obtain a decrease in voltage.

In other embodiments, it should be recognized that the relative positions of the transformer **172** and autotransformer **192** may be reversed in series between the generator **136** and device **10**.

Returning to FIG. **11**, the output power is identified as being set to 75 watts in the generator's bipolar mode of operation. With respect to general-purpose generators currently used in the electrosurgical industry, it has been found that a significant portion of the generators only provide an output power of 50 watts in their bipolar mode, with only a few providing an output power of 70-75 watts in bipolar mode. Above 75 watts, a very small number of generators may provide power in their bipolar mode of 100 watts.

As is well known, the maximum output power of a general-purpose generator in its bipolar mode of operation is lower than the maximum output power of the generator in its monopolar mode of operation. One reason for this is that the electrodes commonly associated with a bipolar device, such as device **10**, are generally in much closer in proximity as compared to the active and return electrodes of a monopolar device, thus reducing the need for greater power. Furthermore, with additional power, use of many prior art dry tip electrosurgical devices only leads to more tissue desiccation, electrode sticking, char formation and smoke generation, thus further obviating the need for additional power.

However, as established above, device **10** of the present invention inhibits such undesirable effects of tissue desiccation, electrode sticking, char formation and smoke generation, and thus do not suffer from the same drawbacks as prior art dry tip electrosurgical devices. Consequently, it has been found that bipolar devices which provide power and fluid to a treatment site may, in certain instances, be able to use significantly greater power than the output power current general-purpose generators offer in their accorded bipolar modes of operation.

General-purpose generators may offer significantly greater output power than 75 watts when set in their monopolar modes. For example, in monopolar "cut mode", the maximum power output of the generator is typically in the range of 300 watts. However, in monopolar cut mode, the voltage and working impedance range are much greater than in bipolar mode. For example, an exemplary high impedance cut-off for a monopolar cut mode is about 1000 ohms. At 300 watts and 1000 ohms, the voltage in monopolar cut mode is about 548 RMS. Furthermore, this voltage may be even higher for generators with a high impedance cut-off above 1000 ohms. For example, certain generators may have a high impedance cut-off in monopolar cut mode of about 3500 ohms at 150 watts. This corresponds to a voltage of about 725 volts RMS.

In order to reduce monopolar cut mode voltage to a desirable level for bipolar use, without correspondingly decreasing the high impedance cut-off, autotransformer **192** may be placed in series circuit configuration between the electrodes of bipolar device **10** and the monopolar mode power output of the generator **136**.

With the introduction of a autotransformer **192** to convert monopolar output power voltages to voltages associated with bipolar output power, preferably the wires **36**, **38**, plug connectors **35a**, **35b** and autotransformer **192** are all assembled and provided in a single housing **43** shown in FIG. **28**, for similar advantages to those discussed in reference to FIG. **25**.

FIG. **28** further illustrates an exemplary electrical configuration which may be associated between device **10** and generator **136**. As shown in FIG. **28**, in this embodiment the wiring within plug housing **43** of device **10** is configured such that hand switch **142a** may be electrically coupled to the monopolar "cut mode" hand switching circuitry of generator **136**. More specifically, as shown hand switch **142a** is electrically coupled to generator **136** upon the insertion of hand switch plug connector **35g** of device **10** into hand switch receptacle connector **137g** of generator **136**.

In other embodiments, the wiring within plug housing **43** of device **10** may be configured such that hand switch **142a** is coupled to plug connector **35h** and plug receptacle **137h**, in which case hand switch **142a** is now electrically coupled to the monopolar "coagulation mode" of generator **136** rather than the cut mode.

In addition to plug connector **35g**, plug housing **43** also contains power plug connector **35e** which may be electrically coupled to the monopolar power receptacle connector **137e** of generator **136**. As shown, upon insertion of power plug connector **35e** into power receptacle connector **137e**, electrodes **64a**, **66a** are now coupled to generator **136**. Finally, as shown, the last connection of device **10** to generator **136** comprises ground pad receptacle connector **35f** being inserted over ground pad plug connector **137f** of generator **136** to couple electrodes **64b**, **66b** to generator **136**.

In other embodiments, as shown in FIG. **29**, the hand switch **142a** may be eliminated and foot switch **142** may be used alone.

In still other embodiments, the autotransformer **192** may be provided as part of an electrical adaptor **200** provided in series between device **10** and generator **136** as shown in FIGS. **30** and **31**. In this embodiment, preferably the adapter **200** includes its own receptacle connectors **202a**, **202b** on one side which are configured to receive plug connectors **35a**, **35b** of device **10**, and on the opposing side has its own plug connector **204e** and ground pad receptacle connector **204f** which are

configured to connect to receptacle connector **137e** and ground-pad plug connector **137f** of generator **136**, respectively.

As shown in FIG **31**, adaptor **200** may also be configured to accommodate device **10** with hand switch **142a**. In addition to the various connectors identified above, adaptor **200** has its own bipolar hand switch receptacle connector **202c** on one side configured to mate with the bipolar hand switch plug connector **35c** of device **10**, and on the opposing side has its own monopolar hand switch plug connector **204g** configured to connect to monopolar "cut mode" hand switch receptacle connector **137g** of generator **136**. Finally, in order to establish the remaining link between the hand switch circuitry and the bipolar power output, the adaptor **200** has a hand switch plug connector **202d** configured to mate with hand switch receptacle connector **35d** of device **10**.

As shown in FIG. **31**, device **10** now includes four connectors (i.e. **35a, 35b, 35c, 35d**) when adaptor **200** is used rather than just the three connectors (i.e. **35e, 35f, 35g**) associated with FIG. **28**. Connector **35d** is added to provide a connection, when mated with connector **202d** of adaptor **200**, to plug connector **204e** which bypasses autotransformer **192**.

Turning to the specifics of autotransformer **192**, similar to transformer **172**, preferably coil **196** of autotransformer **192** comprises #18 magnet wire wound on a toroidal shaped, magnetic core **194**. More preferably the core **194** comprises a ferromagnetic core and even more preferably a ferrite core. Preferably the ferrite has an amplitude permeability in the range of 500 μ to 5,000 μ and more preferably of about 2,000 μ. More preferably, the ferrite comprises ferrite material no. 77.

With autotransformer **192** above, similar to equation (7), secondary voltage may be described as follows:

$$V_s = V_p(N_s/N_p) \tag{8}$$

where:

V_s = Secondary voltage;
V_p = Primary voltage;
N_p = Number of turns (windings) for primary coil; and
N_s = Number of turns (windings) for secondary coil (i.e. number of turns to the tap)

Using the formula above, to bring the primary voltage $\mathbf{V_p}$ of 725 volts RMS down to a secondary voltage $\mathbf{V_s}$ to 150 volts RMS, a step-down autotransformer is used with a turns ratio N_p/N_s of 4.8:1. However, as explained above, the devices of

the present invention may facilitate the use of higher voltages without adverse consequences, due to, among other things, the presence of a fluid provided at the tissue treatment site.

For purposes of the appended claims, the term "tissue" includes, but is not limited to, organs (e.g. liver, lung, spleen, gallbladder), soft tissues including highly vascular tissues (e.g. liver, spleen) and tissue masses (e.g. tumors).

While a preferred embodiment of the present invention has been described, it should be understood that various changes, adaptations and modifications can be made therein without departing from the spirit of the invention and the scope of the appended claims. The scope of the invention should, therefore, be determined not with reference to the above description, but instead should be determined with reference to the appended claims along with their full scope of equivalents. Furthermore, it should be understood that the appended claims do not necessarily comprise the broadest scope of the invention which the Applicant is entitled to claim, or the only manner(s) in which the invention may be claimed, or that all recited features are necessary.

All publications and patent documents cited in this application are incorporated by reference in their entirety for all purposes, to the extent they are consistent.